Search processes in short-term memory

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SEARCH PROCESSES IN SHORT-TERM MEMORY

A. J. P. Hendrikx

STELLINGEN

bij het proefschrift "Search processes in short-term memory"

A.J.P. Hendrikx

Stellingen

1.

In korte-duur geheugentaken, waarin een reeks opeenvolgende items wordt onthouden, komt de recollectie van een enkel item tot stand middels een ophaalproces waarbij gebruik wordt gemaakt van een der direct toegankelijke locaties in de gememoriseerde geheugenreeks. Deze directe toegankelijkheid vloeit voort uit de temporele of subjectieve structuur die tijdens de verwerving aan de geheugenreeks wordt opgelegd.

2.

Ook uit de reactietijden als maat voor de geheugenprestatie blijkt de aanwas van proactieve interferentie over een aantal trials te zijn beperkt tot de interferentie afkomstig van een of twee onmiddellijk voorafgaande trials.

3.

De effectiviteit van precueing in een keuze-reactietaak hangt af van de mate waarin de interne "cues", die door het precue-signaal worden opgeroepen, het ophalen van de relevante stimulus-response alternatieven uit het werkgeheugen bevorderen.

4.

Een uitputtend zoekproces, dat zich binnen een eindig systeem voltrekt, kan slechts uitputtend worden beschreven indien wordt aangegeven onder welke voorwaarden het proces zichzelf beeindigt.

5.

De psychologische Functieleer bestudeert van oudsher de mentale processen van informatieverwerking die ten grondslag liggen aan het intellectuele vermogen van de mens. De verworven kennis en inzichten van dit vakgebied blijken thans onmisbaar bij het optimaliseren van de uitwisseling van informatie tussen mens en computer.

6.

De reiziger die per trein voorbijsnelt aan een spoorwegstation zou, bij verificatie van zijn gegist bestek, geholpen zijn met plaatsnaamaanwijzingen die niet evenwijdig aan de richting der spoorbaan zijn opgesteld.

7.

De organisatorische scheiding tussen wetenschappelijk personeel en ondersteunende diensten bemoeilijkt een doelmatige bedrijfsvoering van het universitair wetenschappelijk onderzoek.

8.

Indien bij verdere bezuinigingen bij het wetenschappelijk onderwijs de voorkeur wordt gegeven aan opheffing van faculteiten boven opheffing van een gehele universitaire instelling, zou de recente naamverandering van de hogescholen in universiteiten gevolgd moeten worden door een operatie in tegengestelde zin, waarbij de universiteiten (weer) hogescholen zouden gaan heten.

9.

De weldadige effecten van "precueing" zijn het beste te observeren op Beursplein 5.

10.

De ontwikkeling van computernetwerken, waarbij het beginsel der "trias politica" niet wordt geëerbiedigd, vormt een gevaar voor een vrije samenleving.

11.

Het collectieve geheugen wordt al te zeer op de proef gesteld bij halfwaardetijden van meer dan 24.000 jaar.

12.

"Enisus arces attigit igneas."

Tilburg, 21 november 1986. A.J.P. Hendrikx

SEARCH PROCESSES

IN

SHORT-TERM MEMORY

Promotor: Prof. Dr. A.F. Sanders

Co-promotor: Prof. Dr. A.J.W.M. Thomassen

SEARCH PROCESSES IN SHORT-TERM MEMORY

Proefschrift

ter verkrijging van de graad van doctor
aan de Katholieke Universiteit Brabant,
op gezag van de rector magnificus, Prof. Dr. R.A. de Moor,
in het openbaar te verdedigen
ten overstaan van
een door het college van decanen aangewezen commissie
in de aula van de universiteit
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door

André Joseph Paulus Hendrikx

geboren te Heerlen

1986

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aan Martijn

aan mijn ouders

Drukkerij Neoprint, Soest

CONTENTS

CHAPTER 1

INTRODUCTION

Chapter 1

INTRODUCTION

This dissertation addresses the question how a person retrieves information from short-term memory. Our ability to remember events that have occurred in the immediate past is an essential attribute of cognitive functioning and crucial to our experience of a continuous flow of time. The significance of this ability is readily apparent if one considers that a series of spoken or written words can be retained long enough to be recognized as a meaningful message. Likewise, a telephone number can be dialled without hesitation after a series of digits has been presented, while a person at the receiving end, having answered the call, still knows what he was doing before the telephone rang. Yet, the fact that memory is also quite fallible is evident from many instances of human error. Memory failure may have dramatic consequences, particularly in complex human-machine systems, where a person deals with large amounts of information from different sources as, for instance, in air-traffic control (e.g. Wickens, 1984).

Short-term memory (STM) refers to situations in which information is first encoded and stored in memory and subsequently, after a short retention interval, the stored information is made available for recall or recognition. Encoding takes place after information contained in the stimulus has been registered in the form of a transient sensory code by our senses (e.g., Sperling, 1960). The result of the encoding and storage process is called a memory trace, which is in itself an unobservable hypothetical entity. The contents of the memory trace set an upper limit to what can be remembered. In STM situations, the retention interval that follows the presentation of the to-be-remembered information is typically short. During this interval, attention can be diverted from the presented information. At the end of the retention interval, the stored information is made available for recall or recognition by means of some kind of retrieval process. STM can thus be described as a particular category of cognitive tasks of relative short duration, quite distinct from long-term memory (LTM) tasks, which refer to our general knowledge and about life episodes experienced in a more distant past.

The first section of this chapter presents an introduction to the present study, consisting of a brief overview of the most important concepts and theoretical notions that play an important part in the investigations reported in the following chapters. The next section --termed "The present study"-- describes the theoretical and methodological points of departure of this study. In the final section of this chapter, the main conclusions of this study are reviewed and summarized.

Fast decay in a short-term store of limited capacity

Short-term memory has been studied in a great variety of tasks. A typical example is the memory-span task, which is used to investigate how many items can be recalled immediately. Recall in this task is perfect as long as the number of about seven items -- the "memory span" -- is not exceeded. Forgetting occurs to the extent that the memory span is exceeded. This task demonstrates a major property of memory, in that it has a limited capacity in STM situations. A second property of STM is the decline of memory performance as a function of time elapsed since the information has been acquired. This can be demonstrated in the Brown-Peterson paradigm, which studies recall of short lists, usually three random consonant letters, as a function of the retention interval, that is, the interval between presentation of the to-be-recalled (TBR) items and the time of recall (Brown, 1958; Peterson & Peterson, 1959). Recall after a short interval remains at a high level as long as the items can be rehearsed. When rehearsal is prevented, however, by instructing the subject to pay attention to a distractor task -- usually some type of arithmetic task -- recall drops dramatically within a few seconds after presentation. Thus it appears necessary to pay conscious attention to a small number of TBR items in order to prevent their being forgotten. This necessity has led to a theoretical notion that has played an important role in theories on STM performance. According to this notion, memory traces suffer from quick autonomous decay and rehearsal prevents decay by restoring the memory trace to its original strength, as if it had been presented anew.

Two different memory systems ?

The limitation on the capacity of memory and its apparent vulnerability to the sheer passage of time contrasts sharply with the properties of memory as revealed in long-term memory tasks. It is evident that a normal person can remember vast amounts of information which can be retained over many years. This divergence provided the basis for a distinction between two separate memory systems with different properties: a short-term store and a long-term store. For example, in Atkinson & Shiffrin's theory (1968), the short-term store has the function of retaining limited amounts of information in a state that can be directly accessed, while additional recoding processes act upon this information so as to transfer it to the long-term store, that is, to transform the information into more permanent memory traces. The main purpose of dual-trace theories was to relate the findings on STM with theories on verbal learning which explained long-term forgetting in terms of interference among associations established at different times. In this latter view, memory consists of a vast and virtually unlimited hierarchical network of associations. Once an association is established, it remains in memory permanently. Forgetting occurs when, at the time of test, the appropriate association is blocked or dominated by a stronger association, so that it cannot become manifest. Forgetting in LTM has been mostly studied in serial and paired-associate tasks. (There is of course a whole "cognitive" memory tradition on semantic memory, sentence verification, psycholinguistic rules, etc., but this is less relevant to short-term memory.) In paired-associate tasks, a long list of paired elements is presented, each consisting of a stimulus term and a response term. At the time of test, the first term of a pair is presented as the stimulus and the correct response consists of the response term to which that stimulus had been paired. When two lists are presented in succession, two types of interference may occur, depending on the similarity of the stimulus terms or the response terms occurring in the respective lists. Associations established in the first list may exert Proactive Interference on the recall of associations from the subsequent list, while recall of the first list, after presentation of the second list, may suffer from retroactive interference from the associations from the second list (e.g., Postman & Underwood, 1973).

The serial-position curve

Dual-trace theory provided an plausible explanation of some very robust phenomena observed in another STM task, called free recall. In this task, a supra-span list of unrelated words is presented in succession and recalled in any order. The proportion of correct recall for every word is measured as a function of its serial position, that is, its order of presentation. The serial postion curve is U-shaped, indicating superior recall of the first and the last items. This primacy and recency advantage gradually levels off for items at more interior serial positions so that the central region of the curve shows an asymptotic level of recall. According to dual-trace theory, the most recent items are still held in short-term store at the time of recall and, hence, they can be recalled directly. The remaining items are recalled from the long-term store, although their trace strengths vary, since their opportunity to be rehearsed in the short-term store during presentation gradually decreases as more items have been presented before. Thus, the primacy effect occurs by virtue of greater opportunities for rehearsal of the first few items, before they are displaced by later items, when the memory span is exceeded (e.g., Glanzer, 1972).

Supporting evidence for the dual-store explanation of the serial-position curve stems from experiments showing that experimental variables have a selective effect on different regions of the serial-position curve. The primacy and central regions are sensitive to list length and degree of meaningfulness of the items, while the recency region is not affected. A similar selective effect is found for presentation rate, confirming the view that the contribution to recall performance of the long-term store strongly depends on the time available for rehearsal and recoding during presentation. Conversely, the recency effect vanishes with delayed recall if rehearsal is prevented by inserting a distractor task (Postman & Phillips, 1965). The latter effect is similar to the fast forgetting in the

Brown-Peterson task and thus confirms the view that the recency effect reflects a contribution from the short-term store.

Levels or domains of processing

Yet, the last two decades have shown a fundamental shift away from dual-store theory towards a more unitary view of memory. First, Craik & Lockart (1972) proposed a "levels of processing" theory to account for the observed differences in persistence of memory traces in terms of differences in perceptual encoding processes. The amount of information recalled is a function of the type of processing required during learning. Thus, instead of two distinct types of memories with different dynamical properties, memory representations are the product of various types of encoding processes which may occur simultaneously. Each encoding process performs a progressive transformation on the input that may be more or less elaborate. As a result of this multiple-encoding process, a memory trace consists of encodings at various levels and in various degrees of elaboration. The various types of processing levels provide different representations of the same input, such as acoustic or visual features and semantic attributes. The levels vary on a continuum of "processing depth". Deeper levels of processing, such as semantic encoding, provide more permanent traces. Subjects may adopt different processing strategies, depending on the type of task and, hence, long-term and short-term recall may be differentially affected, depending on the degree of elaborateness of the encoding level that contributes most to recall in either long-term or short-term tests. Baddeley (1982) has advocated a more general but related concept of "processing domains". In this view, a stimulus can be processed within various domains simultaneously, in a parallel, heterarchical manner (such as in terms of words and visual images), rather than in a hierarchy of levels.

Hyde & Jenkins (1969) demonstrated a differential effect of encoding on recall in an incidental learning situation, in which recall of words was unexpectedly tested after subjects rated these words on some dimension requiring either semantic encoding (i.e., pleasantness) or a lower level of encoding (for instance, by checking whether the word contained a certain letter). Recall performance depended on the type of rating task: With deeper encoding, recall was as good as in a condition of intentional learning, where subjects did have advance knowledge of the recall test while performing the same rating tasks. Hence, the nature of the rating task determined the type of encoding, which in turn determined what could be recalled at a later time.

Recency reconsidered

A second challenge to dual-trace theory consisted of Bjork & Whitten's (1974) discovery of the "long-term recency effect": When a distractor task intervenes between the presentation of a list and free recall, the usual elimination of the recency effect does not occur if short periods of distractor activity are inserted between the list items themselves. This persistence of the recency advantage under conditions which should impair the contents of the short-term store demonstrates that the recency advantage does not reflect highly accessible, albeit fragile, traces. Bjork & Whitten proposed instead that at the time of delayed recall, an item becomes less distinctive from other items in its temporal vicinity. Hence, it becomes increasingly difficult to discriminate, at the time of recall, between the temporal attributes of the various items. The various durations between the occurrences of items and the present serve as temporal attributes. This explanation contrasts with passive decay as a function of time, and as well with the notion of displacement from short-term store by more recent items -- the major explanations of short-term forgetting in dual-trace theory. Since the same principle of temporal discrimination can be used to explain short-term and long-term recency effects, this view denies the necessity of a separate short-term store (Crowder, 1976).

Interference in short-term memory

A third line of evidence that questioned the dual-trace interpretation of memory evolved when it was discovered that proactive interference (PI) appears to govern forgetting in the Brown-Peterson paradigm. Since the laws of interference had traditionally been based on LTM tasks, the presence of similar interference phenomena in STM cast doubt on the distinction between separate long-term and a short-term memory systems. Keppel & Underwood (1962) measured the retention of a trigram of three consonant letters in a short sequence of trials, as a function of the retention interval and separately for each trial. There was no forgetting across the retention interval in the first trial, while forgetting grew stronger as a function of the number of previous trials. Thus, in the first few seconds after learning, forgetting was due to a buildup of PI with a growing number of previous trials, presented in close succession. One way to explain fast forgetting across the retention interval would be to refer to the classical notion of learning theory, according to which there is spontaneous recovery of associations learned in previous trials, as time elapses after learning the current trigram. Whereas the decay interpretation of short-term forgetting implied that forgetting occurs during storage, as a gradual deterioration of the memory trace, the interference explanation left open another possibility: since interference could exert its effect by inhibiting <u>retrieval</u> of an intact trace. Thus, the "retrieval hypothesis" denies that there are fundamental differences between forgetting in STM and LTM.

Yet, beside the retrieval hypothesis, there is a second explanation of STM forgetting in terms of PI, the "storage hypothesis". This hypothesis states that previously learned associations interact with newly formed traces during storage, thus causing a permanent loss of trace strength. This position has been elaborated in the "Acid-bath theory" by Posner & Konick (1966). New items entering memory are submerged in an acid bath, the acidity of which depends on the similarity of new and older traces. The degree of interference is assumed to depend on the acidity and on the duration of the bath (i.e., the retention interval).

Evidence against the storage hypothesis and in favor of the retrieval hypothesis was presented in a series of studies (Wickens, 1972; Wickens, Born & Allen, 1963), demonstrating a particular form of improved recall, termed "release-from-PI." These studies used a paradigm in which a few Brown-Peterson trials test delayed recall for one type of material (say, letters). These trials are followed by a "release trial". In the release trial an entirely different category of TBR material is used (say, digits). Wickens <u>et al.</u> found that, before the shift in stimulus vocabulary, recall declined steadily over trials, while recall in the release trial suddenly recovered to the level observed at the first trial which was free from PI. The finding that PI is restricted to memory for the same type of material is in line with both the storage and the retrieval hypothesis. However, in a final free-recall test of all items, subsequent to the Brown-Peterson trials, there was no superior recall of the material from the release trials (Watkins & Watkins, 1975; Loftus & Patterson, 1975). This lack of permanence argues against the storage hypothesis: if the decline of recall in the Brown-Peterson trials was reflecting decreasing trace strengths, this should also have been manifest in the final test. These results also exclude an interpretation of PI in terms of differential encoding, in the sense that there is enhanced and more elaborative encoding during the first trial following an idle interval, as well as during a release trial, due to the novelty of the stimuli. In contrast, the retrieval hypothesis accounts for the equal results in the final test, since all items have comparable degrees of discriminability: the privileged position of release trials relative to preceeding trials no more exists, and release trials also interfere amongst one another.

The notion that PI originates from discrimination problems during retrieval can be extended to temporal discriminations between memory traces of successive trials, so as to explain two further findings in the Brown-Peterson task: First, no more than three prior trials contribute to the buildup of PI (Loess, 1964) and, second, if trials are separated by a pause of at least two minutes, PI virtually disappears (Loess & Waugh, 1967). According to Weber's psychophysical law, increasing the intertrial interval will increase the discriminability of the times elapsed since the trials occurred. In addition, Bennett (1975) provided evidence that the crucial factor on which PI depends, is the time of presentation of the previous interfering items, relative to the time at which the TBR items were presented. Bennett studied what happened when the item from the current trial had to be recognized, with an item from a prior trial serving as a distractor. Since the correct item and the distractor item were presented at the time of test, memory strengths of both the correct and incorrect item were equated. The probability of incorrect recognition turned out to be an inverse function of the temporal separation between the original presentation of the distractor and the current trial. This finding questions the concept of memory strength of the competing items as a sufficient explanation of proactive interference. Instead, it suggests that the crucial factor underlying PI is a loss of temporal distinctiveness.

A study by Gardiner, Craik & Birtwistle (1972) provided strong evidence for the retrieval process as the locus of PI, rather than either encoding at the time of aquisition or the fate of the memory trace during storage. Using the Brown-Peterson paradigm, Gardiner et.al. introduced very subtle shifts of semantic category in the release trial that were not noticed by a control group and did not cause release from PI. When the distinctive feature of the release material was pointed out to the subjects, release did occur, and it made no difference whether the shift was revealed before presentation of the shifted material or immmediately prior to recall. Thus, release from PI occurred by virtue of facilitation at the time of retrieval: For the disctinctive feature of the release material to be effective it should be available at the time of retrieval.

The above line of reasoning on the origin of PI effects in terms of discriminations among some type of temporal tag or list marker has much in common with the explanation proposed by Bjork & Whitten for the recency effect in free recall.

Accessibility and discriminability of memory traces

The notion of temporal discrimination was elaborated by Anderson & Bower (1972) on the basis of studies on list differentiation. They argued that the ability to identify in which list, among other presented lists, a certain item had occurred, cannot be solely based on memory strength, in the sense that items from more remote lists would have less strength. Instead, Anderson & Bower proposed that recall consists of a generation phase and a recognition phase. A candidate memory trace is first accessed and, subsequently, the trace is either rejected or recognized as the TBR item. The recognition phase of recall does not evaluate memory strength but rather a "list marker" that has been associated with the item during list presentation.

The question remains whether a decrease in discriminability between current and previous traces is the only way in which traces interfere. Alternatively, PI may impair retrieval because of difficulties in accessing the appropriate trace (cf. Anderson & Bower's "generation process"). Are previous traces merely distractors, impeding a choice among competing traces, or do they obstruct the right trace from being considered at all ? Dillon (1973) addressed this question by presenting, at the time of test, the items from the previous Brown-Peterson trials, so as to preclude discrimination errors. Recall did not improve, suggesting that PI impedes the accessibility of the items from the last trial. A similar conclusion was drawn in a study where there was no need for a discrimination between successive trials since subjects were to report after each trial all items presented in any trial so far (Dillon & Thomas, 1975).

There is also strong evidence from a study by Tulving & Pearlstone (1966) showing that recall failure is due to the absence of proper retrieval cues, rather than to impaired encoding or storage. Lists of TBR words, belonging to a number of different categories were presented. The category name preceded all words belonging to that category. In a cued recall test, each category name was again presented as a recall cue, whereas in a control test, subjects recalled without the aid of category names. Cued recall was by far superior to uncued recall, indicating that the unrecalled words in the control condition were available in memory but not accessible. Hence, recall strongly depends on accessibility, which is determined by the type of retrieval cues present at the time of test. Tulving & Patterson proposed that learning is the acquisition of retrieval cues and that the major task of a theory of memory is to discover how these retrieval cues operate. Hence, two major principles seem to underlie memory performance: On the one hand, the type of retrieval cues available at the time of test are of decisive importance. On the other hand, different types of encoding of a certain event are possible at the time of acquisition, as underlined by the notion of "levels of processing" (Craik & Lockart, 1972).

The interdependence of these principles has been advocated by Tulving & Thompson (1973) in their formulation of the principle of "encoding specificity:"

> "What is stored is determined by what is perceived and how it is encoded, and what is stored determines what retrieval cues are effective in providing access to what is stored."

Elaborating on this view, Baddeley (1982) has proposed a distinction between two types of contextual effects during acquisition. An "interactive context" co-determines the encoding of the stimulus, whereas an "independent context" is coded separately from the stimulus, although context and stimulus are associated. As a consequence, reinstating the interactive context as a retrieval cue will enhance both recall and recognition, whereas an independent context cue may only be helpful in recall.

Positional cueing theory

The common picture emerging from the above sketch of recent notions on short-term memory is that an important underlying cause of memory failure consists of difficulties in the discriminative identification of the appropriate memory trace and from an inability to access (i.e. "generate") the right trace with the aid of the retrieval cues available at the moment of testing. According to Tulving & Thompson (1973):

> "remembering is regarded as a joint product of information stored in the past and information present in the immediate cognitive environment of the rememberer. It is also becoming increasingly clear that remembering does not involve a mere activation of the learned association or arousal of the stored trace by a stimulus. Some sort of a more complex interaction between stored information and certain features of the environment seems to be involved in converting a potential memory into conscious awareness of the original event and corresponding behavior."

This point of view is the basis of the positional cueing theory (Sanders, 1975) which was the main guideline in devising the experiments reported in the following chapters. The main features of positional cueing theory are concerned with particular types of retrieval cues that become associated with a series of to-be-remembered events. When a number of TBR items is presented in succession, a positional primacy cue becomes associated with the first item, as a perceptual anchor point. The primacy cue is not affected by list length or properties of subsequent items or events. As presentation of the list progresses, positional recency cues are associated to the last few presented items. Sanders assumes two or three recency cues, which decrease in strength with more remote serial positions. This is illustrated in figure 1, panel A. The recency cues shift with the presentation of new items, irrespective of whether they belong to the TBR list or to interpolated material during a retention interval. Thus, the recency cues remain associated with the "psychological present".

During retrieval, direct access to any item from the list is only mediated by the positional cues. Once access is obtained, however, the first retrieved item serves as a retrieval cue for a subsequent item, by virtue of interitem associations. This theory explains the phenomena of short-term recall as discussed in the above review, such as the U-shaped

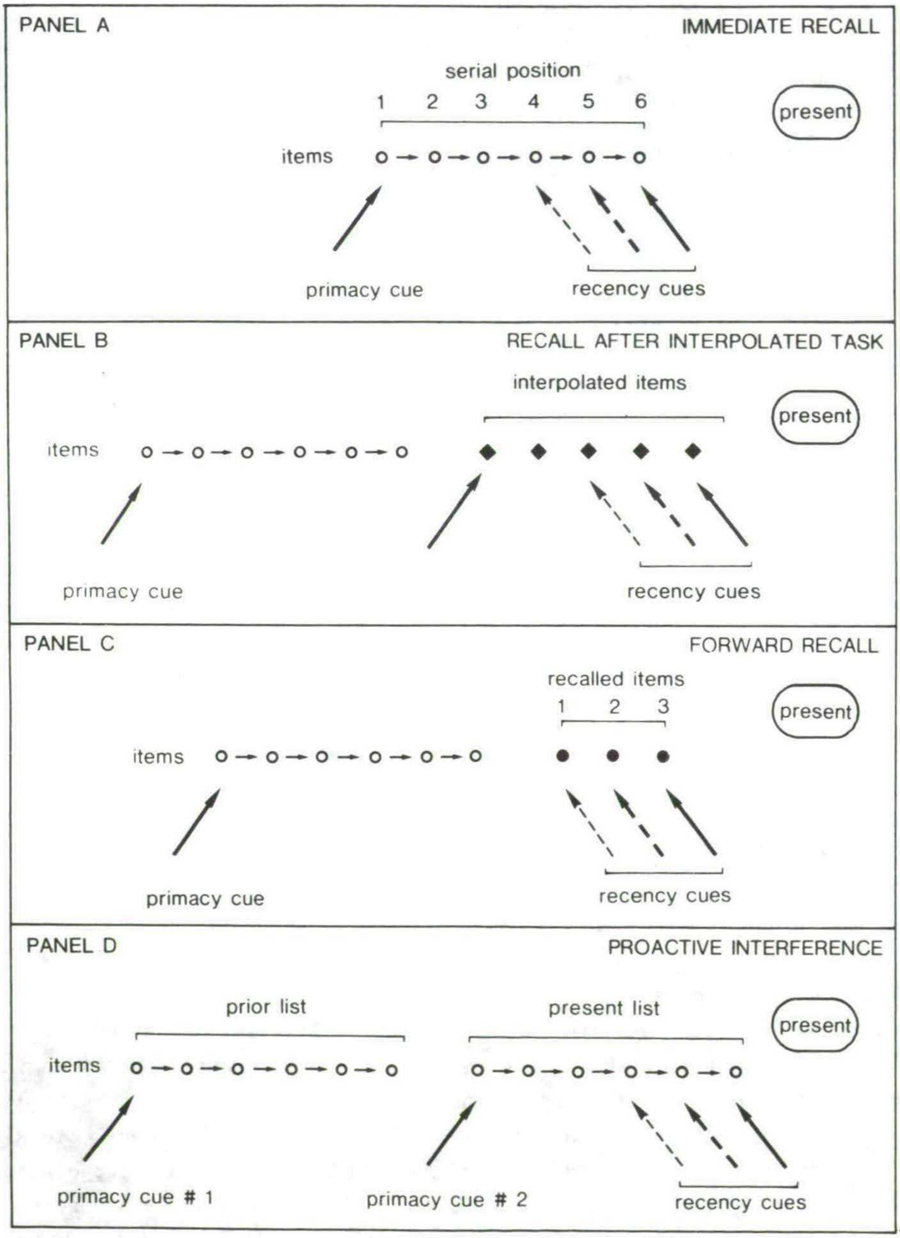

Figure 1: Positional primacy and recency cues in short-term memory.
Open circles refer to successive presentation of to-be-remembered items.
Arrows represent positional cues acting as retrieval cues.

serial position curve in free recall, the selective effects of task variables on the various regions of the serial position curve, the effects of PI in Brown-Peterson tasks and the release from PI obtained with either longer intertrial intervals or shifts in material. These explanations will be briefly sketched below and discussed further in the following chapters. It seems useful to mention here how the positional cueing theory accounts for the shape of the serial position curve.

The recency advantage is due to direct access to each of the last few items by means of recency cues. The recency advantage disappears with an interpolated task during the retention interval since the recency cues shift away from the last few TBR items. This is illustrated in panel B of figure 1. The primacy advantage is due to direct access of the first item, followed by forward inter-item serial search. It is not supposed to directly suffer from interpolated recall (see figure 1, panel C). Yet, it may be possible that a somewhat longer period of interpolated material affects the temporal discimination of successive lists, which in turn would affect recall of the first item. The low asymptotic recall level in the central region of the serial-position curve reflects the fact that retrieval of these items require a an increasingly longer retrieval pathway. Consequently, later items run an increasing risk of becoming inaccessible by associative search errors. Furthermore, the theory explains PI in terms of confusion between primacy cues of successive lists (see panel D of figure 1). Hence, PI is predicted to have a selective effect on the primacy and central region of the serial-position curve.

Since positional cueing theory provides an account of retrieval in terms of processes occurring in succession, the predictions derived from this theory can be stated in terms of the duration of the retrieval process, as revealed by reaction times.

Reaction times in probed recall

In the present experiments, memory performance is mainly measured in terms of reaction times (RT), in contrast to most studies mentioned above, which measure the number of memory failures ("proportion correct"). Thus, the present study focusses on the measurement of the duration of succesful retrieval. The measurement of RT as a technique to reveal properties of mental processes dates back to Donders (1868) and has regained much interest in recent years, since Sternberg (1969 a) proposed the Additive Factor Method as a way to analyse and interpret RT as consisting of the sum of the durations of serial and independent stages (see also Taylor, 1976; Sanders, 1980). Basic to this approach is the notion that human information processing occurs by way of a number of specific operations performed on the information to be processed. The nature of these operations depend on the particular characteristics of the task under investigation. For a given task, the entire sequence of operations occurs within a chain of successive stages, in which the output of one stage is the input of the next stage. Operations performed within different stages are assumed to be independent, in the sense that the output of any stage is not affected by task variables. The duration of the processes within a stage is a function of task variables. The model assumes that two or more task variables affect a common stage when the effects of these variables on the RT interact. On the other hand, when task variables have additive effects on RT, the model predicts that the variables affect different stages.

Application of this analytical tool to a recall task requires presentation of a single stimulus -- a probe -- at the time of test, indicating which part or element of the acquired material should be recalled, and also defining the onset of the RT interval. The RT interval is terminated by vocal recall of a single item.

The present experiments will mainly use a positional probe, indicating the serial position of a single TBR item in the list in which it was presented. The probe is a light in a horizontal array of positions, the leftmost position indicating the first serial position in the list, the second-to-left position indicating the second serial position, etc. (see top half of figure 2).

The positional-probe technique is designed to test single-item recall at each serial position. Single-item recall is free of output interference, which may occur when all items from the list are to be recalled. Secondly, this technique focusses on the retrieval process resulting in succesful recall.

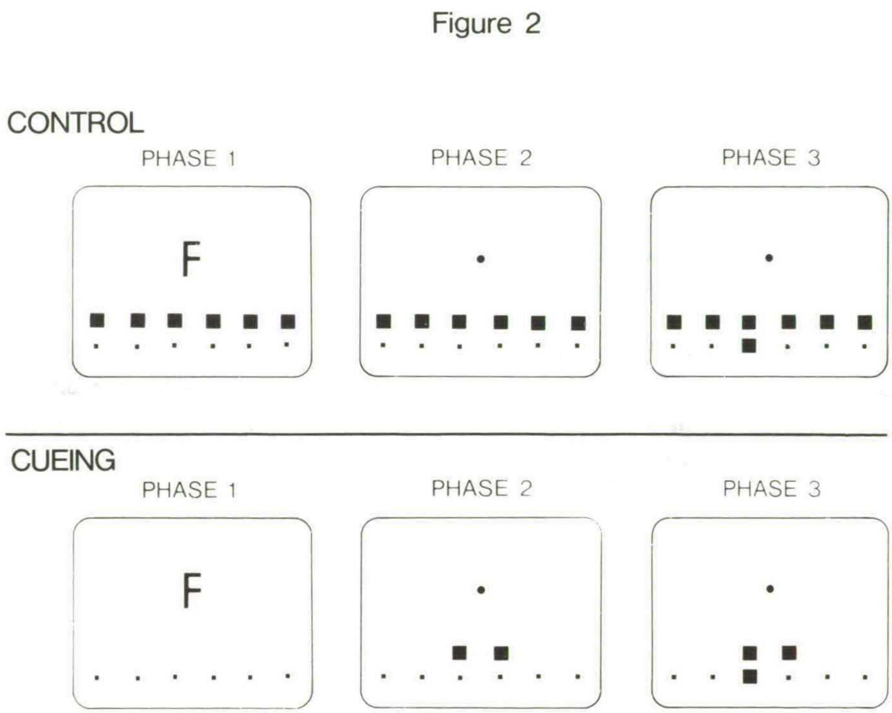

Figure 2: Three phases of a trial.
In the upper half of the figure, the continuous display of six luminous dots indicates the number and the serial position of the to-be-remembered items. Phase 1: Successive presentation of the letter items at the center of the screen. Phase 2: Presentation of a so called "control signal" above the dot row briefly in advance of probe presentation. The control signal serves as a temporal warning signal. Phase 3: Presentation of the positional probe at one location in the dot row, indicating that the third serial position is requested for recall. In the lower half of the figure, the "cue signal" is presented instead of the control signal. The cue signal -- or "precue signal" -- consists of luminous squares at two or three positions above the dot row, indicating that the probe can only occur at one of these cued positions.

In contrast, the more traditional measure of "percent correct" only counts instances of successful recall. Thirdly, the measurement of RT is particularly useful with sub-span lists, since it avoids ceiling effects which may occur with the percent-correct measure.

A potential problem for the positional probe technique lies in the possibility that recall latency is differentially affected by some perceptual factor, due to the various probe positions in the array of possible probe locations. Welford (1973) has shown that choice RT can be affected by the spatial position of the action signal, as well as by the number of signal alternatives. Hence, two studies, reported in Chapter 3 and Chapter 8 investigated this problem. These studies will be briefly reviewed at the end of this chapter. It was concluded from these studies that recall latency as a function of serial position, as obtained with the presentation technique employed in the present studies, reflect genuine retrieval effects, rather than effects on probe encoding (see figure 3). Hence, the positional probe technique employed here is considered as suitable for the investigation of memory retrieval.

Figure 3

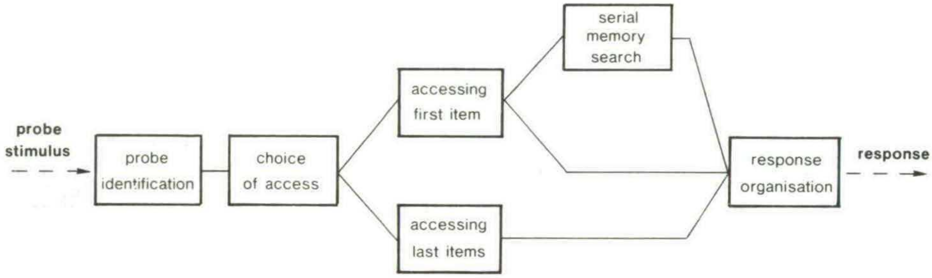

Figure 3: A tentative flow diagram of the retrieval process.
The first process is termed probe identification. It is initiated in response to a positional probe. The next process determines the choice of the point of direct access to the list. The bifurcation reflects access to either the first item of the list by means of the primacy cue or to one of the last items by means of the recency cue. Access to the first item may be either followed by an iterative process of inter-item search for an item at the second or later position, or by responding to the first item.

Chapter 1

THE PRESENT STUDY

It is the aim of this study to investigate the properties of short-term retrieval by testing some hypotheses on the duration of the retrieval process. These hypotheses are derived from positional cueing theory. The flow diagram in figure 3 is a first attempt to represent the retrieval process in positionally probed recall, as proposed by this theory. The retrieval process may be conceptualized as a number of serial processing stages. In the same vein as Sternberg's (1969 b) serial search model for recognition memory, the first stage consists of perceptual encoding of the probe. The output of this stage is input to a choice process which determines the point of direct access to the list. The choice of this point determines the retrieval pathway which leads to the item at the probed position. Subsequent to the choice stage, the diagram bifurcates, the upper part referring to retrieval from the primacy and central region of the list, whereas the lower part of the diagram refers to retrieval from the recency region. On the basis of a serial-stage model of information processing, the model predicts a monotone increase of RT across serial positions in the primacy and central region and a decrease of RT across the last items. This has indeed been observed in a study by Sanders & Willemsen (1978). These authors obtained a bow-shaped serial-position curve for RT. They observed, in the first part of the list, an increase of RT across serial positions, with a slope of about 200 msec/item. This suggests that the forward serial search is essentially slower than the search rates of about 40 msec/item obtained by Sternberg (1969 b) in a recognition test.

Chapter 1 The Present Study

Effects of subjective grouping of the TBR items

The primacy cue and the recency cues constitute an organizational structure of memory in which temporal anchor points play a major role. It is well established that providing a temporal structure to the list is very helpful to recall, even when the conditions preclude chunking (e.g. Laughery & Spector 1972; Ryan, 1969 a, b). Temporal structure can be provided by inserting pauses during list presentation, or by subjective organization on behalf of the subject. Therefore, the experiment reported in Chapter 2 tests the hypothesis that subjective grouping creates an additional recency and primacy cue at the boundary between two sublists. These additional cues may provide direct access to the boundary items, in the same way as the positional cues at either end of the list. When a list is divided into two sublists, each group of items can be accessed from either end, and, therefore, recall latency and error rate for boundary items will decrease. Furthermore, the additional primacy cue at the beginning of the second sublist should be stronger than the cue at the beginning of the first sublist, while the recency cue at the end of the first sublist should be weaker than the recency cue at the end of the list. Consequently, recall latency and accuracy at these positions should be likewise affected. In addition, latency and accuracy of the first and the last item should not be affected by grouping, since direct access to these items is not changed. The predictions of positional cueing theory are confirmed by the results reported in Chapter 2. These results also suggest that the effect of subjective grouping does not result from recoding of the sublists into higher-order units (chunking), since substantial differences exist between items within groups with respect to the size of the grouping effect. Thus, the beneficial effects of organizational structure in memory do not necessarily imply recoding of groups of elements: Organizational structuring is possible at the level of the individual item.

Precueing of the positional probe

The model is further tested in Chapter 3 by investigating the effects of precueing. In a precueing condition, a precueing signal is presented briefly in advance of the positional probe.

The precue indicates the subset of positions in which the probe will occur. Thus, the precueing signal reduces the number of possible probe positions (see lower half of figure 2). In some conditions of the experiment, the lists were structured by subjective grouping. In the remaining conditions, subjects were instructed to refrain from grouping.

Chapter 3 shows that, for ungrouped lists, precueing substantially reduces recall latency but does not affect accuracy. Moreover, the precueing advantage is of equal size at all serial positions. These results suggest that precueing preactivates a stage of retrieval that is common to all serial positions. In other words, it appears that the reaction process is facilitated by advance activation of a retrieval stage. In line with this view, there is no effect of precueing on accuracy, which also suggests that precueing does not enhance the availability of retrieval cues, but merely preactivates these cues.

In terms of the model presented in figure 3, the most plausible retrieval stage to be preactivated by precueing is "direct access." Preactivation of direct access could occur either by means of the primacy cue or the recency cue, or both. This interpretation of precueing is supported by the results on structured lists: Precueing effects are vastly different across serial positions (SPs) when lists are subjectively grouped. The beneficial effects of precueing are eliminated when the two SPs at either side of a group boundary are precued. Similarly, when an early and a late SP are precued -- by a non-adjacent cue -- precueing is only beneficial at the most recent SP, while <u>adverse</u> or no effects are observed for the early item. These results suggest that precueing only preactivates a single positional cue at a time. Consequently, this one-sided preactivation is a disadvantage for the item that cannot be retrieved via the preactivated point of access. When the preactivated pathway is inappropriate, the retrieval process must be aborted and this tends to increase recall latency and errors. The finding that this principle is equally valid for the two extreme positional cues as for additional retrieval cues at a group boundary, confirms the conclusion of Chapter 2 that additional retrieval cues, created by grouping, share the properties of the primacy and recency cue. In conclusion, the research reported in Chapter 3 indicates that the bifurcation in the diagram in figure 3 represents a choice between mutually exclusive retrieval pathways. In other words, access to a memorized list is obtained only at a single point at a time, while the structure imposed on the list determines which points of access are available.

Chapter 3 also discusses the predictions concerning the effects of grouping by Estes' Perturbation theory (1972), which assumes a hierarchical non-associative memory structure. According to this theory, stored information is preserved by cyclic reactivations, and forgetting is the result of perturbations of order information. The observed specific pattern of grouping benefits across the serial-position curve are at conflict with this theory. Hence, with the present experimental task, there is no need to postulate an extra hierarchical level in the coded representation of grouped lists, as in Estes' theory. It is concluded that beneficial effects of grouping can also occur with a linear organizational structure of the memory list.

The experiments in Chapter 2 and 3 lead to the conclusion that precueing does not change, but rather preactivates the retrieval pathway. Consequently, precueing does not improve recall accuracy but it does cause faster recall. Yet, Chapters 2 and 3 show this only for the case of a fixed 300-msec interval between the precue signal and the probe. The experiment reported in Chapter 4 investigates this hypothesis for longer intervals. It was found that prolonging the interval between the precue and the probe does not promote recall accuracy, but it does further reduce RT. These results are in line with the conclusions of the preceding studies using a short and fixed precueing interval. The time course of the precueing effects over increasing durations of the precue-probe interval also demonstrates a contrast between the primacy cue and the recency cue: whereas the primacy cue is not directly associated to the second item, the recency cue is indeed related to the penultimate item (i.e., the fifth item in a six-item list). This is reflected in the finding that the precueing effect at the second serial position (SP 2) tends to become greater than at SP 1 with longer intervals, suggesting that inter-item serial search can already start with larger intervals. In contrast, the precueing advantage for SP 5 is greater than for SP 6, irrespective of interval duration. These contrasting results are well in accord with positional cueing theory. Precueing is more beneficial at SP 5 than at SP 6 due to the weaker bond of the recency cue to SP 5. Since both SP 6 and SP 5 are directly accessible, this difference exists irrespective of interval duration, while SP 2 can only be retrieved by activation of its association with SP 1, requiring a time-consuming search. Consequently, there is a progression of the precueing effect at SP 2 over time, which has not been observed for the directly accessible first item.

It is further argued in chapter 4 that the present findings on precueing effects in probed recall are problematic for the "Search of associative memory" (SAM) theory, as proposed by Raaijmakers & Shiffrin (1980). According to this theory, prerecent items are retrieved by means of a cue-dependent search of an associative memory network. In particular, this theory cannot easily accomodate the adverse effects of precueing certain serial positions of a grouped list (Chapter 3) as well as the finding that even with longer precue-probe intervals, precueing does not promote recall accuracy (Chapter 4).

Proactive interference (PI)

Positional cueing theory explains PI effects in short-term memory in terms of inter-list confusion between the positional primacy cues of successive lists. Hence, interference by a previous list should only affect direct access to the first item. This view predicts that recall latency and accuracy of all items from the primacy and central region of the SP-curve will be affected by a constant amount, while recall of the most recent items will not be affected.

These predictions on latency have been confirmed in a study by Sanders & Willemsen (1978), using a positional probe technique. Chapter 5 presents an experiment which replicates this finding and which also has tested the hypothesis that PI depends on the similarity of the first item of successive lists. Since the first item is regarded as a retrieval cue for the second item, the first item is crucial to recall of those items retrieved by way of forward serial search. The experiment was run in pairs of closely-spaced trials -- a "non-PI trial" and a "PI-trial" -- and trial pairs were separated by a longer interval, to allow for dissipation of PI (e.g., Turvey & Weeks, 1975). In the control condition two lists of consonants had to be recalled. As expected, PI causes an increase of RT to the same extent for all but the last few trials. In the experimental conditions, the similarity between the two lists was increased by substituting a prefix (the digit "8") for the first letter item, or, alternatively, similarity was decreased by substituting the prefix in either the first or the second list only. The results confirm the prediction that the PI effect increases when both lists have a prefix, while PI tends to be smaller with a prefix in only one list. Also, PI effects are restricted to the first half of the six-item list, as predicted.

The study reported in Chapter 5 also replicates the finding of Sanders & Willemsen (1978) that, in the first trials, RT to the final item is longer than to the first item, whereas in the PI-trial about equal latencies are observed at these positions. This finding provides a contrast with the studies reported in Chapters 2, 3 and 4, which consistently show a substantial faster RT to the most recent item as compared to the first. In these studies, many trials were presented in close succession. This raises the question whether PI accumulates over a larger number of trials than has been suggested by studies using the traditional -- and possibly less sensitive -- measure of proportion correct. Therefore, the experiment reported in <u>Chapter 6</u>, investigates the buildup of PI within strings of six closely-spaced trials, again using recall latency of positionally probed recall. In line with the common finding on PI with traditional measures, the main effect of PI occurs in the second trial of the strings, without any clear effect in later trials. Hence, the notion of a buildup of PI across longer trial strings can be rejected. A subsidiary finding is that the length of the first list does not affect the size of the PI effect, which confirms a prediction of positional cueing theory. It is further concluded that the relative long recall latencies at the first SP as compared to the last SP, observed with massed trials, as reported in chapters 2, 3 and 4, may have been caused by a shift in attentional bias towards the recency part of the list, rather than resulting from extended buidup of PI or prolonged practice. With massed trials, acquisition of new input may improve at the cost of reduced storage, causing a trade-off in performance between the first and the last section of the SP-curve.

<u>Testing recognition with positional probes</u>

An experiment on the effect of grouping and cueing on item <u>recognition</u> is reported in <u>Chapter 7</u>. The experiment employed an item-recognition task in which a list of items was sequentially presented, followed by an item probe, or "test item", (cf. Sternberg, 1969 b). Subjects were asked to decide whether or not the probe matched one of the memorized items. RT of the yes/no decision was measured as a function of list length (set size) and as a function of serial position.

The memory lists contained either 2, 4 or 6 items. The probe was either positive or negative, that is, the probe item either matched or did not match one of the list items. The results show that RT is a linear increasing function of set size and that the set-size functions for positive and negative probes are parallel. This finding confirms the results of a number of studies on memory scanning (see Sternberg, 1975), which have been taken as evidence for a fast, serial and exhaustive item-to-item search through memory. According to this exhaustive search model, one memorized item is compared at a time with the probe, and search proceeds untill all of the memorized items have been processed, regardless of whether a match occurs during search.

The experiment reported in Chapter 7 intends to test some predictions of the exhaustive serial model. It also tests some alternative predictions of rival models, such as self-terminating serial search, parallel search and direct-access models. The predictions concern the effects of serial position of the matching item, effects of grouping the list into sublists and effects of precueing one sublist of a grouped list. In the grouping condition of the experiment, the memory lists were temporally structured by inserting a pause during the successive visual presentation of the TBR items. In the cueing condition, one of the temporally defined sublists was precued, so as to indicate that a match could only occur in the precued sublist. (The terms cueing and precueing are interchangeable).

Although the linear and parallel set-size functions, as observed in the control condition (no grouping, no cueing), are well in accord with exhaustive serial search, RT depends strongly on serial position. These effects are similar to the bow-shaped SP-curves obtained in positionally probed recall, as reported in Chapters 2 through 6. Serial-position effects are at odds with an exhaustive serial-search model as proposed by Sternberg (1969 b), since all list items must be searched, irrespective of the serial position of the matching item. In addition, the beneficial effects of grouping and cueing are also hard to explain with a serial-search model.

The results also show that grouping substantially reduces the intercepts of the set-size functions for positive as well as for negative probes. Cueing enhances the beneficial effect of grouping, but only for positive probes. It is argued that an exhaustive serial-search model predicts a grouping advantage for positive probes, but no advantage for negative probes. The advantage for positive probes is expected because a pause between sublists provides a logical termination point, that allows the search to be restricted to one sublist, at least when a match occurs in the sublist that is searched first. However, exhaustive serial search does not predict the observed grouping advantage for negative probes, since both sublists must be searched before deciding that there is no matching item. The major alternative serial model, the self-terminating model, does not predict a grouping advantage, since search terminates upon encountering a match, irrespective of sublists. In short, the results obtained in Chapter 7 argue against serial-search models of short-term recognition, as well as against parallel-search models, for a number of reasons. (A full discussion is presented in Chapter 7.)

The effect of serial position of the matching item in the memory list is drastically altered by grouping. This modulated SP-curve resembles the effect of subjective grouping in positionally probed recall, in that the items at boundary positions between sublists have the largest grouping benefits. Instead, the results provide support for a direct-access model (e.g., Baddeley & Ecob, 1973), in which there is no search at all through the memorized list. It is proposed, in agreement with the direct-access view, that the memory representation of the probe item is accessed directly. Direct access of an item is followed by retrieval of its contextual attributes and a subsequent decision whether or not the retrieved attributes are sufficiently strong to issue a positive response. In this view, grouping provides additional contextual cues, which aid the decisional process, whereas cueing preactivates the contextual cues relevant to the recognition of the probe item.

It is concluded from the experiment in Chapter 7 that the principles governing retrieval in immediate recall, as formulated in positional cueing theory (Sanders, 1975), also provide a valid description of retrieval processes within a direct-access model of item recognition. In probed recall, the positional primacy cue and recency cues guide direct access to the first item or to the last few items. In item recognition, positional cues are retrieved via direct access to an item probe. Subsequently, the retrieved cues facilitate the decisional process as to whether or not the probe occurred in the memory list.

Methodological precautions: Precueing in recall and in choice reactions

A possible methodological problem for the positional-probe technique is investigated in Chapter 3 and Chapter 8. As mentioned before, Chapter 3 investigated the effect of precueing on probed recall, by presenting a precue signal briefly in advance of the positional probe. Precueing reduces the number of possible probe alternatives, by indicating the relevant subset of locations from a linear array of lights. It is reasoned that without precueing, the perception of the probe signal could be differentially affected by the locations of the probe signal in the array of probe lights (see upper half of figure 2). As a result, perceptual artifacts in the serial-position curve for recall latency could possibly occur. These artifacts can be eliminated by reducing the spatial uncertainty, by precueing the relevant section of the array briefly in advance of probe presentation (see lower half of figure 2). In case such artifacts are actually present, a successful elimination of the artifacts by precueing should be reflected in a different shape of the serial-position curve in a precueing condition as compared to a control condition without precueing. Experiment 1 reported in Chapter 3 shows that precueing does not reshape the SP-curve, although there is a substantial reduction of recall latency across all SPs. It is therefore concluded that probe location does not produce perceptual artifacts in SP results.

As to the question of the origin of the beneficial precueing effects in probed recall -- as observed in the experiments reported in Chapters 3, and 4 -- it has already been argued above that precueing effects reflect preactivation of memory search, rather than an advantage of perceptual probe encoding. This assertion is supported by evidence provided by the series of four experiments in Chapter 8, in which precueing effects are studied in choice-reaction tasks. Converging evidence from these experiments indicate that the effectiveness of precueing is mainly determined by factors related to reponse selection processes, rather than perceptual factors. Hence, there is no reason to expect perceptual factors to play a large part in probed recall latency. Furthermore, the size of the precueing effect in the probed recall task of Chapter 2 is rather substantial (about 200 msec), as compared to the precueing effects observed in the experiments on choice reactions reported in Chapter 8. For instance, in the first experiment, the reduction of RT amounts to about 50 msec for the pointing task and about 30 msec for the naming task, when a subset of two out of six alternatives are precued. It is plausible to assume that a perceptual factor is unaffected by the type of responding, so that the smallest precueing effect obtained is composed of a possible perceptual factor and a residual effect of facilitation of response selection. Therefore, the most cautious conclusion is that these results rule out the possibility of perceptual effects of precueing greater than the effects observed in the naming task (30 msec).

In conclusion, Chapters 3 and 8 allow us to regard the precueing effects on recall latency as reflecting facilitation of memory retrieval. This conclusion implies preactivation of direct access, on the basis of further evidence in experiments 2 and 3 of Chapter 2. Secondly, the differences between recall latencies at different SPs can be considered as resulting from differences in the speed of memory retrieval.

Chapter 1

MAIN CONCLUSIONS

The main conclusions of the present study can be stated as follows:

(a) Retrieval in short-term memory can be described as a combination of direct access and forward serial search. Direct access is provided only by means of positional cues associated to items at particular serial positions.

(b) The positional primacy cue is uniquely associated to the very first item of the list. The positional recency cues are associated with the last few items, with increasing strength for more recently presented items.

(c) Subjective grouping of a list of successively presented items is not a matter of recoding a group of items into a higher-order unit, but rather a matter of creating additional positional cues by means of which retrieval pathways are altered. As a consequence, the latency of recall is reduced and accuracy is improved. Thus, organizational structuring of the memorized list is possible at the level of the individual item representation.

(d) The measurement of reaction times in short-term memory appears to be a useful and unique research tool. This is demonstrated in the study on the combined effects of grouping and precueing on latency and accuracy of probed recall, since grouping is found to affect both variables, whereas precueing affects only reaction time.

(e) When precueing restricts the range of serial-position alternatives of the to-be-recalled item briefly in advance of probe presentation, memory retrieval is preactivated. This preactivation consists of selecting one point of access to the list. In case of preactivation of direct access to the first item, longer intervals between the precue and the probe may also preactivate a subsequent serial interitem search. As a result, precueing promotes the speed of the retrieval process.

(f) Direct access to a memorized list can occur only by means of one positional cue at a time.

(g) Since precueing does not affect accuracy, preactivation of direct access, as prompted by precueing of the relevant probe position, does not provide an additional retrieval pathway.

(h) Interference between lists is a matter of interference between positional cues.

(i) When latency is used as a measure of recall, there is no evidence for buildup of proactive interference over more than one or two previous trials. This confirms the common finding with traditional recall measures, based on recall failures.

(j) Performing in a great number of closely-spaced trials of immediate probed-recall causes a shift of attentional bias, away from the primacy region of the lists and in favor of the recency region. This shift is not the result of a prolonged buildup of proactive interference, nor of prolonged practice.

(k) In short-term item recognition, the effects of list length (set size), of the serial position of the matching item, of temporal structure of the memory list, of precueing a sublist, and of the presence, respectively the absence, of the probe item in the memory list, are adequately explained by a direct-access theory, according to which there is <u>no</u> search among the memorized items, whereas serial-search models or parallel models are at odds with most of these effects.

(l) The action signal in choice-reaction tasks can be conceived of as a retrieval cue for recall of the representation of the proper response which is stored in a limited capacity memory stack (Theios, 1973; 1975). When the set of relevant signal-response alternatives is reduced by means of presentation of a precue signal, the search priorities of the memory stack are rearranged in advance of the actual processing of the action signal. As a result, precueing promotes speed and accuracy of responding. The facilitation caused by precueing crucially depends on "cue compatibility", a factor affecting the process of rearrangement of the stack. Thus, precueing effectiveness is a matter of proper retrieval cues, by means of which the contents of the memory stack are rearranged.

(m) Cue compatibility is a twofold concept, which refers to the "naturalness" of the encoded spatial relations between (a) features of the precueing signal and attributes of the memory representations of the responses, and (b) between features of the precueing signal and features of the action signal.

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CHAPTER 2

EFFECTS OF GROUPING ON RECALL LATENCY

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EFFECTS OF GROUPING ON RECALL LATENCY *

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Subjects vocalized lists of six visual consonant letters for the immediate probed recall of a single item. They were instructed either to vocalize all items in a monotone way or, alternatively, to read the third and sixth item with an inflected voice. Thus, subjects were encouraged either to treat all items as a single group or as two smaller groups. Rival predictions on recall latency were tested, derived from (a) positional cueing theory (Sanders 1975), and (b) perturbation theory (Estes 1972). Reaction time (RT) of vocal recall of a single item was measured as a function of its serial position (SP). The position of the requested item was signalled by a positional probe presented immediately after the list. The probe initiated the RT interval. In the monotone condition, RT and error rate were bow-shaped functions of SP. Voice inflection greatly reduced mean RT and errors at SP 3, 4 and 5, in particular at SP 4. However, there were no effects at SP 1, 2 and 6. It is argued that voice inflection causes grouping of the items. The data partly contradict the perturbation model, which explains effects of SP and grouping in terms of loss of order information during storage. The results generally support positional cueing theory, which states that auxiliary cues are created at the boundary between the two groups. These cues facilitate retrieval of middle-of-the-list items. Speed and accuracy of recall suggest that an item associated to a positional cue can be retrieved by fast direct access, whereas other items must be retrieved by a time consuming serial search. Hence, grouping creates additional pathways for retrieval rather than changing the storage mode.

It has been well established that drastic improvements are obtained in tests of immediate recall when subjects are instructed to divide the list subjectively during presentation into groups of adjacent items (e.g., Wickelgren 1967). Similar improvements are observed when items are explicitly presented as groups, as, for example, when the item sequence is segmented by inserting short temporal pauses or by rhythmical patterns (e.g., Bower and Winzenz 1969; Ryan 1969a, b). Generally, items within a group tend to be either recalled or forgotten together. This paper attempts to contribute to the question how such organizational factors affect short-term retrieval. In contrast to earlier studies, which have relied upon measuring recall failures, the present experiment investigates the latency of successful recall of a single item from a list.

Most theories dealing with the organizational structure of memory have assumed that memory for serial events is organized as some kind of nested hierarchy, rather than as a linearly organized chain of inter-item associations. For instance, grouping of items could result in recoding the items of a list into a smaller number of "chunks" (Miller 1956). Recoding is conceived of as a translation of several individual item representations into a single and more efficient higher-order code. For example, random strings of letters could be substituted by a pronounceable or meaningful unit (e.g., Johnson 1970, 1978). Chunks are supposed to function as single units in learning and memory.

Yet, chunking is not the only possible way of establishing a structure in memory. Laughery and Spector (1972) have pointed out that grouping might occur in an altogether different manner, in which the original item representations are retained. These authors showed that under conditions designed to preclude chunking, by way of rapid presentation of unrelated consonants, temporal grouping still had a beneficial effect on immediate ordered recall. The case in question was that when the same list was repeatedly presented, but with a different temporal structure, recall still improved over repetitions. This argues against chunking, since no improvement is expected with repetition in different chunks (see also Bower and Winzenz 1969). Another instance of grouping without chunking was reported by Ryan (1969a, b), who showed that large reductions in order errors occur when the list is broken up by the introduction of short pauses between the presentation of some of the items. Lengthening the pauses did not affect this result, which again argues against an explanation in terms of chunking. Ryan reported that three items constituted an optimal group size. Wickelgren (1967) also found that, irrespective of list length, rehearsal in groups of three successive items produced optimal ordered recall. He suggested that subjects have a finite number of positional concepts, such as "beginning" and "end", which aid in encoding order. Thus, associations to positions may fix the order, not only of items within a group, but also of item groups. In addition, inter-item associations contribute to ordered recall. In a similar vein, Neisser (1967) has emphasized the importance of rhythm as a structure to which items are attached and which serves as a retrieval cue. Recently, these views have been elaborated in "positional cueing theory" (Sanders 1975), and, alternatively, in a structural theory on memory organization known as "perturbation theory" (Estes 1972; Lee and Estes 1977, 1981).

It is the purpose of this paper to evaluate these rival theories on grouping and on the cause of serial-position effects in immediate recall.

Positional cueing theory

In this theory, it is assumed that during retrieval, access to the list can be obtained by means of positional cues, i.e., a *primacy* cue connected to the first item and a *recency* cue connected to the last few items. Both types of positional cues may be regarded as temporal anchor points, that provide direct access, either to the first item or, respectively, to one of the few last items. The recency cue becomes temporarily associated to each item as it is presented, since that cue is fixed to the "psychological present". Therefore, with greater distance of the to-be-remembered item from the end of the list, the strength of the association to the recency cue decreases and consequently, there is a decreasing probability that the recency cue is available for that particular item. Hence, only the last few items can be retrieved by means of direct access via the recency cue, and this is so only on some of the occasions for the prerecent items. The items of a list that cannot be directly accessed are retrieved by a forward serial search following access to the first item. The search is guided by inter-item associations. This theory can account for the well-known bow-shaped form of serial position curves for errors in ordered recall. In the first part of the list, error probability is expected to increase across serial positions, since serial search implies a cumulation of the chance of a failure of inter-item associations. The decrease of recall errors for the final items of a list is explained by the increasing number of opportunities of direct access by means of the recency cue. In support of these views on memory retrieval Sanders and Willemsen (1978) have shown that *latency* of probed recall of a single item is a similar bow-shaped function of serial position. These results suggested direct access to be a fast process, in contrast to the relatively slow serial search of which each step is thought to contribute a certain amount of time to the duration of the retrieval process.

Positional cueing theory explains beneficial effects of grouping as a result of increased accessibility of the list which is due to auxiliary positional cues at the boundary between successive groups. More specifically, in a grouped list there will be an auxiliary recency cue for the last item of the earlier group and an auxiliary primacy cue for the first item of the next group. As a result, each group of items can be directly accessed at either end. Direct access to the first item of a group leads the way to a forward serial search within the group. Alternatively, the last item of that group, and possibly the penultimate item of that group as well, are directly accessible by means of the recency cue of that group. The strength of that recency cue will depend on the position of the group, i.e., it will be less for earlier groups, due to interference from later groups. Hence, the accessibility of the last and the penultimate position within a group depends on the ordinal position of that group within the list. It is predicted that the additional means of access for grouped lists cause beneficial effects at specific serial positions. Thus, in the simple case of grouping a list of, say, six items into two equal sublists, positional cueing theory does not predict an appreciable effect of grouping on the first items of the first sublist, since their retrieval depends on the original primacy cue in both conditions. The same argument holds for the final item of the list, which always depends on the original recency cue. However, the remaining middle-of-the-list items should clearly benefit from the auxiliary positional cues that demarcate the boundary between the two groups. In particular, for a six-item list, the theory predicts beneficial effects of grouping on recall latency for the boundary items at SP 3 and SP 4. The strength of the auxiliary recency cue at SP 3 will be less than the recency cue at the end of the list, due to interference from the latter cue. Therefore, in grouped lists, performance at SP 6 will be better than that at SP 3. For the same reason, it is unlikely that the advantage of the auxiliary recency cue extends backwards to SP 2. Hence, no substantial effect of grouping is expected at that position. With respect to SP 5, grouping is expected to be fairly beneficial, in case the backward association with the recency cue at the end of the list is not available. In the latter case, there is an effective alternative retrieval pathway, i.e., direct access at SP 4 followed by an inter-item search from SP 4 to SP 5. Of course, this alternative type of retrieval of SP 5 in a grouped list will be superior to the alternative for an ungrouped list, i.e., forward serial search from SP 1 to SP 5.

In short, positional cueing theory expects substantial grouping effects at SP 3 and SP 4, while it predicts hardly any effect at SP 2 and a fair effect at SP 5. As said, no effects of grouping are expected at SP 1 and SP 6.

With respect to comparisons *among* serial positions in grouped lists, positional cueing theory expects the following ordinal relations. As said, performance at SP 6 will be better than at SP 3, since the early recency cue at SP 3 will be weaker than the later recency cue. For analogous reasons, SP 4 is expected to be superior to SP 1. Obviously, SP 6 will be superior to SP 4. Furthermore, it is predicted that the "late" auxiliary primacy cue at SP 4 will lead to better performance than the "early" recency cue at SP 3, due to substantial differences in strength. The entire set of ordinal predictions is given in fig. 1. In that fig., there is a large range of indifference for SP 3, since only SP 6 and SP 4 are expected to be definitely superior to SP 3. Similarly, SP 5 may have any ordinal relation to SP 1 as well as to SP 3.

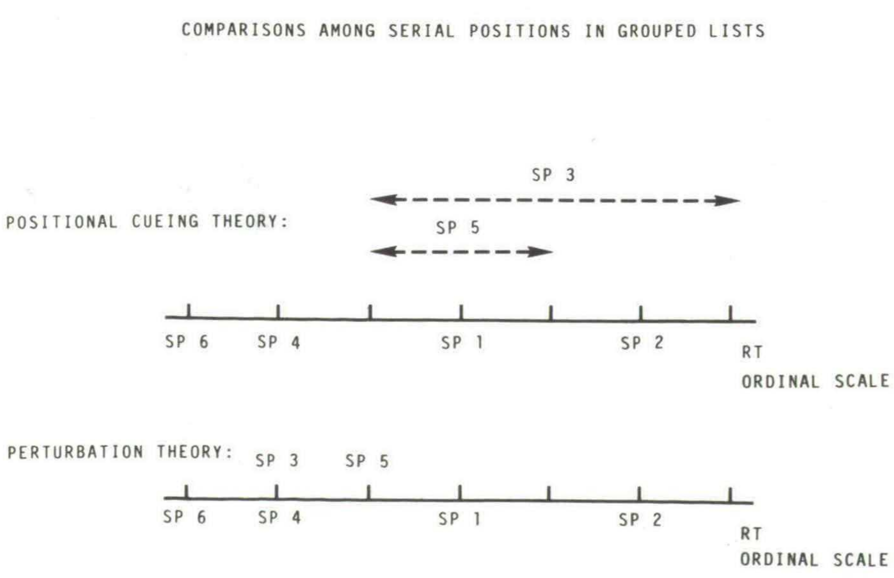

Fig. 1. Predicted ordinal relations among mean RTs of serial positions (SP) in the inflected condition (i.e., for grouped lists). A dashed line indicates that for a given SP, no particular ordinal relation is predicted with SPs falling within that range.

Perturbation theory

Estes (1972) has proposed a structural model in terms of hierarchical encoding (see also Lee and Estes 1977, 1981). This model is designed to explain effects of grouping and of serial position in terms of storage loss of order information. Unlike "horizontal" associative models based on direct inter-item relations, such as positional cueing theory, the Estes model is "vertical" in the sense that it assumes that all items are connected to superordinate control elements. The control elements are hierarchically organized. At a certain level of organization, items, or item groups, are coded as control elements. At each level of the hierarchy, the control elements are temporally ordered. Therefore, all relations between the items in a list depend on whether they share common control elements. This hierarchical structure has important implications for the way memory will be searched when retrieving a particular item. Obviously, search in a vertical structure will be quite different from the way retrieval would be guided in a horizontal structure.

The Estes model assumes that a control element is set up at each discontinuity of the input sequence. Thus, an ungrouped list will simply be coded as a single contextual control element to which all individual items are attached. The order of the items is preserved by a cyclic reactivation of each memory element. Hence, the reverberatory activity reflects, at each coding level of the hierarchy, the original presentation order of the elements. It is further assumed that random perturbations of the cycle times cause advances or delays in the reactivation time of a given element. This results in interchanges in the order of reactivation. At the level of the item representations, perturbations will thus cause positional errors in recall. Furthermore, it is expected that at the feature level, perturbations among the constituent features of the items cause deficiencies of the item representations. Eventually, this may lead to omissions due to unrecognizable codes or to recall of an incorrect item. However, in immediate recall of a near-span list the number of perturbations will be relatively small and, therefore, they would not necessarily cause overt recall errors. Nevertheless, loss of order information at the feature level could be detectable as an increase of retrieval duration, in much the same way as signal degradation prolongs choice reaction time (Frowein and Sanders 1978). Hence, it is expected that effects on accuracy will be accompanied by strong effects on latency.

When a list is grouped in, say, two parts, the Estes model assumes that the two sublists are represented by separate ordered control elements at the intermediate level, each of which is attached to the control element for the entire list. The individual items within a group are all attached to the appropriate control element at the intermediate level. In recall, the "tree" is decoded from top to bottom. As a consequence, retrieving the first item of a grouped list would involve an extra step in the top-to-bottom decoding of the structure.

In the Estes model, forgetting in immediate memory is caused by disturbances of the order of elements subordinate to a particular control element. Such perturbation errors are conceived of as an all-or-none random exchange of positions between adjacent elements. In each unit of time, there is a certain probability for a perturbation to occur. Therefore, items in a list suffer from perturbations as a function of the time interval in between presentation and the attempt to recall. Hence, in immediate recall the recent part of a list will have an advantage over the early part. Furthermore, the Estes model implies that the first and the last element of an ordered array are privileged, as these can only migrate in one direction, whereas the remaining items suffer from perturbations in both directions. In addition, shorter sequences will generally be recalled better, since there is a greater chance that successive perturbations are cancelled out. As a result of these properties, the model is able to explain the bow-shaped error curves for ordered recall, as well as the asymmetry in that type of data in favor of the most recent part of the list (e.g., Lee and Estes 1977).

It follows from the Estes model that grouping will be particularly beneficial for items at the boundary between groups. For instance, when a six-item list is organized into two equal sublists, recall should improve substantially at SP 3 and SP 4. Both items are located at a group boundary and, hence, they will suffer only from perturbations in one direction. In contrast, the third and fourth item of *un*grouped lists are strongly subjected to perturbations, as they are at some distance from the end of the sequence. Hence, large grouping effects are expected. On the other hand, a similar advantage for grouped lists is not expected for the first and final item, since these items are privileged in grouped as well as in ungrouped lists. With respect to SP 2 and SP 5, it is expected that grouping improves recall at both positions due to the fact that the items each belong to a shorter sequence. Furthermore, these improvements should be of about equal size, because SP 2 and SP

5 occupy comparable positions with respect to the item sequence in both grouped and ungrouped lists. At any rate, the model predicts that, in the inflected condition, results at SP 5 will be superior to those at SP 2, since the latter position is subjected to perturbations during a longer retention interval.

Apart from these beneficial effects of grouping, it may be argued that an extra hierarchical coding level for grouped lists implies that at the time of retrieval an additional step in the decoding operation will be required. As a consequence, grouping may cause an effect of increased reaction time over all serial positions. The presence of such a general effect can be assessed at SP 1 and SP 6, since at these positions no other effects of grouping are expected. In case of such a general increase of reaction-time level, the predicted beneficial effects of grouping on reaction time at serial positions 2 through 5 may become obscured. However, any predictions about performance differences *among* serial positions of grouped lists – as will be outlined below – would not change, due to the constancy of the effect across serial positions. Besides, the specific effects of grouping on *accuracy* would also remain, since only latency would be generally affected by grouping.

In short, perturbation theory predicts that, in case grouping does not increase recall latency at SP 1 and 6, there will be beneficial grouping effects, but only at SP 2 through 5. In case of prolonged latencies at SP 1 and 6 in grouped lists, these increments are expected to be equal and, secondly, some of the beneficial effects at SP 2 through SP 5 might become obscured.

With respect to comparisons of recall *among* serial positions of grouped lists, a number of predictions can be derived from perturbation theory, as summarized in fig. 1. In view of the fact that both SP 1 and SP 3 are privileged in grouped lists, the Estes model would predict that both are superior to SP 2. In addition, reaction time at SP 3 will be smaller than at SP 1, due to its more recent position in the list. Analogous predictions hold for SP 4, SP 5 and SP 6. In general, the model predicts that within any three-item group, such as ABC, recall latency will increase in the order C-A-B. In addition, there is hardly any difference to be expected in the performance level at SP 3 and SP 4, since both positions coincide with a group boundary while their retention interval hardly differs.

The present experiment

The present experiment was aimed at testing the predictions of the rival theories, as outlined above, on the effects of grouping on latency of positionally probed immediate recall. As argued above, the two theories mainly differ with respect to three issues: (a) whether reaction time and accuracy will decrease at SP 2 as a result of grouping, (b) whether performance at SP 3 will be inferior to SP 4 in grouped lists, and (c) whether performance at SP 3 in grouped lists is necessarily better than at SP 1 and SP 2.

For this purpose, reaction time (RT) was measured to a positional probe which was delivered immediately after presentation of a six-item list. The probe indicated the serial presentation position of a single to-be-recalled (TBR) item. RT was defined as the time elapsing between the presentation of the probe and the initiation of vocal recall. This paradigm allows measurement of recall latency as a function of serial position. Moreover, single-item recall precludes effects of output interference. Grouping was manipulated by instructing the *S*s to pronounce the items during list presentation either with or without voice inflection at positions 3 and 6. Since the main interest of this study focussed on grouping in primary memory, the task was deliberately designed to preclude chunking of items and to minimize the role of rehearsal. Therefore, the task involved immediate probed recall of a single item from a list consisting of six random consonant letters, presented successively at a high rate. Vocalization of the items prevents extensive and cumulative rehearsal during presentation (Sanders and Moss 1973), and it forces *S*s to process each item in a similar way. However, the particular properties of the present task, such as vocalized visual items and a linear probe array may encourage particular encoding strategies, emphasizing positional properties of items that may affect the generality of the results obtained with the present task. Nevertheless, the basic effect of serial position on recall latency has been reproduced for the auditive and visual modality and for silent presentation conditions (Sanders and Willemsen 1978; Sanders and Moss 1974), as well as for probed recall of item position (Moss and Sharac 1970).

Method

Subjects and tasks

Nine male and eleven female *S*s, between 19 and 28 years of age, were randomly assigned to either the monotone or the inflected group ($n = 10$ for each group). *S*s were paid for their participation and had no previous experience in memory experiments.

In each trial a list of six consonants was visually presented in succession at a rate of 2 items/sec. All letter lists were randomly composed from the subset: F, J, K, L, M, P, R, T, Z. The list of consonant letters was followed by a probe signal that occupied one of six positions marked out by a display of six dots in a horizontal row. The probe signal indicated the SP of the TBR item, i.e., position 1 through 6 from left to right. The six probe positions were equiprobable. The *S* was required to pronounce the probed consonant as quickly as possible upon presentation of the probe signal and to minimize errors. RT was measured from the onset of the probe to initiation of the vocal response. This task was run under two conditions of intonation mode labeled 'inflected' and 'monotone' in a between-groups design.

The *monotone* group was instructed to articulate all letters of a list in as much the same way as possible, without stressing a letter or changing voice inflection. In the *inflected* group *Ss* were required to stress the third and sixth item – i.e., to voice these letters differently and louder – but to avoid introducing a delay between item 3 and 4. *S*s were continuously monitored on their articulation and were reminded of the instructions between trials, if necessary. In both groups, *S*s were encouraged to adopt a rate of speech similar to the rate of presentation.

Apparatus and display

The *S* was seated in a dimly lit sound-attenuating room and faced a computer-controlled scope (Digital GT-40), at a distance of about 130 cm. Trial onset was signalled by a 500 msec tone of 2900 Hz (65 dB). Simultaneous with the tone, seven luminous dots appeared on the screen. All dots were about 1 mm in diameter. One dot was located 17 mm above the centre and served as a fixation point. The six remaining dots were equidistant (11 mm) and appeared during the entire trial in a horizontal row, at 35 mm and symmetrically below the fixation point. The six locations occupied by the dots signified from left to right the serial positions 1 through 6 of the TBR items. One sec after the warning signal, 6 capital letters were presented in sequence (2/sec) in the area of the display that was centered on the fixation point (height 22 mm, width 11 mm). Exposure time for each letter was 100 msec, but it remained visible for about 300 msec due to the phosphorescence of the scope. During the remaining 200 msec inter-stimulus-interval (ISI) between the successive letters, the letter area remained blank. The last letter was followed after a 500 msec delay by a control signal, consisting of six lights (width 2 mm, height 4 mm) positioned 8 mm above the permanently visible row of six dots. The control signal merely served as an additional warning signal for the probe which was presented 300 msec later. The probe consisted of a single light (2×4 mm) randomly located at one of the six positions in the row of dots. The probe was presented for 2.5 sec at about twice the subjective brightness of the normal display. After the simultaneous offset of the probe and the control signal there was an interval of 4 sec before the warning signal of the next trial occurred.

Procedure and design

Each intonation mode (i.e., monotone and inflected) was assigned to a particular group. Each *S* participated in four sessions preceded by a training session. Each session consisted of one block of 60 trials, preceded by 3 warm-up trials. Four different sequences of 60 six-letter lists were used. There were no repetitions of letters within a list, nor did any letter occupy the same SP in any two succeeding lists. For each sequence of 60 lists, the SP of the probe signal was specified for each list in such a way that (a) each SP was probed 10 times, (b) a probed position did not occur more than twice in successive lists, (c) probe signals did not point to the same consonant more than twice in succession, (d) each letter from the set of consonants was probed once at each SP, with some minor deviations. Two 60-list sequences were composed in this way. In order to counterbalance various sequential effects, a mirrored variant of each of the two sequences was also employed. In the mirror-image sequence, the order of the letters in each list was reversed and the order of the lists was reversed. Furthermore, the SP of the probe in each reversed list was mirrored relative to the middle of the list and thus the probe kept pointing towards the same consonant as in the original list. Each list sequence and its mirrored variant were used once for each *S*. Summed over four trial blocks, this yielded 40 RT measurements per *S* at each SP, about equally divided over the nine letter alternatives. This minimized possible artefacts in the onset of the RT-interval due to differences in the pronunciation of the consonants.

The first session was entirely devoted to practice. First, *S*s practiced a 6-item memory span task with ordered written recall. Stimulus materials and presentation procedures for this task were grossly identical to those of the experimental task. Subsequently, there were 60 practice trials on the experimental task, with knowledge of results on speed and accuracy between trials. The experiment proper was run for each *S* in four 30 min sessions that were separated by 30 min breaks. Each session contained 60 experimental trials [1].

Results

Fig. 2 presents the SP-curves of mean RTs of correct trials and of error rates, for each intonation mode and separately for the first and second half of the experiment. Both measures are averaged over *S*s. A comparison between the right and left panel shows that the results are very stable across sessions, with an exception for SP 4 and SP 5 in the monotone condition, where a substantial reduction of RT is observed in the second half of the experiment. The curves of error rates roughly follow those of mean RTs in both conditions, so that there is no evidence that effects on mean RTs reflect speed-accuracy trade-off. In the monotone condition, the SP-curve for mean RTs and error rates both have an inverted U-shape. The inflected condition produces an SP-curve of mean RTs consisting of two bow-shaped parts. At serial positions 1, 2 and 6 the inflected and monotone conditions are remarkably similar in mean RTs and error rates, indicating that the two groups of *Ss* perform the memory task at an equal level of proficiency. However, at the middle-of-the-list positions, there is a marked decrease of RTs due to the inflected mode of intonation, particularly at SP 4.

A $2 \times 2 \times 6$ ANOVA was conducted on individual mean RTs, with intonation mode as a between-groups factor and with sessions (first vs second half) and SP (1–6) as repeated factors. All main effects were significant (Intonation: $F(1,18) = 14.6$, $p < 0.01$; Sessions: $F(1,18) = 31.5$, $p < 0.001$; SP: $F(5,90) = 36.1$, $p < 0.001$). The interaction between effects of Intonation and SP was highly significant ($F(5,90) = 12.9$, $p < 0.001$) and the interaction of effects of Sessions and SP reached moderate significance ($F(5,90) = 2.5$, $p = 0.03$). The remaining interactions were not significant.

A comparison between the left and the right panel of fig. 2 reveals that the effect of

[1] In each session, two blocks of trials were run, separated by a 2-min break. However, only one of the blocks in each session was run under the condition described above. The present paper only deals with that part of the experiment. Typical of that condition was that in each trial the control signal was presented (i.e., a row of 6 lights). The remaining block of each session was run under the "cue condition", in which a cue signal was presented instead of the control signal, consisting of only two lights. The cue signal provided advance information about the possible probe locations. The results of the cue condition will be discussed in a future paper. The order of conditions within a session was counterbalanced over subjects.

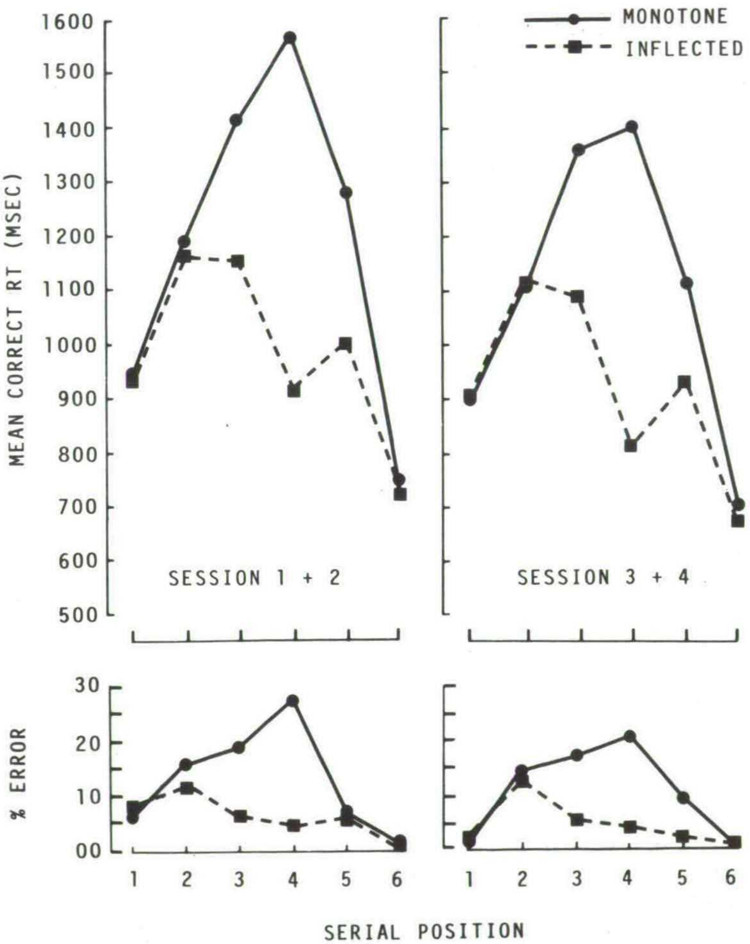

Fig. 2. Mean reaction time (RT) of correct recall and error rates, as a function of serial position, in the monotone and the inflected condition, averaged over 10 subjects in each condition.

sessions is relatively large at SP 4 and SP 5. A 2 × 2 ANOVA was performed on individual mean RTs at the four middle-of-the-list positions (2–5), in the monotone condition only, with Sessions (first vs last half) and SP (2 and 3 vs 4 and 5) as variables. Within each level of SP, the data of the two separate SPs were treated as repeated measures. Of the main effects, only Sessions was significant ($F(1,9) = 19.3$, $p = 0.02$). The interaction of the effects of Sessions and SP was moderately significant ($F(1,9) = 4.8$, $p = 0.05$), which confirms the observation of stronger time-on-task effects for SP 4 and 5 as compared to SP 2 and 3.

An ANOVA on individual mean RTs in the inflected condition, averaged over sessions, with serial positions as single factor, showed a significant effect of SP ($F(5,45) = 37.9$, $p < 0.0001$). Pairwise comparisons among SPs of mean RT in the inflected condition were conducted by means of Scheffé-tests ($df = 5,45$, MS-error = 7208.6). All comparisons indicated significant differences ($p < 0.01$) except for four pairs of positions that were far from significant ($p < 0.20$), i.e.: SP 1 and 4, SP 1 and 5, SP 2 and 3, and SP 4 and 5.

Discussion

The results show strong beneficial effects of intonation mode on speed and accuracy of recall. The effects are restricted to three middle-of-the-list positions which clearly suggests that in the inflected condition, subjects organized the lists into two groups. There is a striking discrepancy between the size of the grouping effect among the three affected positions. As will be argued, some of the results in the inflected condition pose a problem for perturbation theory, in particular with respect to the size of the grouping effect at some serial positions and, secondly, with respect to performance differences among serial positions in grouped lists.

Both the inflected and the monotone condition show the best performance at the two extreme serial positions, while there is no difference between these conditions. These results are in accord with both positional cueing theory as well as perturbation theory. In addition, both theories can accommodate the bow-shaped serial position curves obtained in the monotone condition.

With respect to positional cueing theory, the results support the notion of fast direct access to the first and last item of the list in both intonation conditions. Furthermore, the results on the middle-of-the-list positions fully support this theory. No effect of grouping occurs at SP 2, since that item is retrieved via the first item of the list. This was expected because the auxiliary recency cue at SP 3 is not as strong as the later recency cue at SP 6. The latter cue provides direct access to SP 5 on only a number of occasions. The earlier recency cue at SP 3 will extend backward to SP 2 to a lesser extent, and it will therefore not substantially affect SP 2. The theory also predicts that voice inflection causes beneficial effects for the three remaining middle-of-the-list positions, due to the demarcation of the groups by auxiliary positional cues. The results on speed and accuracy indeed show the expected pattern at SP 3, 4 and 5.

More specifically, with respect to recall latency, the relatively small reduction at SP 3 suggests that at the time of recall, the auxiliary recency cue is relatively weak. This is in line with the notion that the recency cue attached to the terminal item interferes with the earlier auxiliary cue at the time of recall. In contrast, the large reduction at SP 4 suggests that voice inflection establishes a strong auxiliary primacy cue, associated to the first item of the second group. Its strength is due to its late occurrence in the list, relative to the primacy cue of the first group of items. The auxiliary primacy cue at SP 4 provides direct access, which is superior to retrieval via serial search from the beginning of the list. Voice inflection also causes a substantial decrease of RT at SP 5, which suggests that in the grouped lists the fifth item is retrieved by a process of serial search, following direct access of SP 4. Apparently, retrieval of the fifth item via the strong middle-of-the-list cue is effective over and above the direct backward association to the final recency cue. These results confirm the predictions of positional cueing theory on the effects of grouping across serial positions.

Fig. 2 also confirms that recall latency for SP 4 tends to be lower than the level observed at SP 1, as the "later" positional cue will be the stronger. Although this difference does not reach statistical significance, significance is obtained for analogous predictions regarding comparisons between SP 6 and SP 3, and between SP 4 and SP 3. In short, these results confirm the predictions of positional cueing theory with respect to performance differences among serial positions in grouped lists (see fig. 1).

It is also in accord with positional cueing theory that the increase in mean RT is roughly linear over the first four positions in the monotone condition. This result is in good agreement with that of Sanders and Willemsen (1978) and with estimates of the rate of implicit speech (Landauer 1962). The notion of serial search is also supported by the steady increase in errors across these SPs. However, in contrast to the uniform results on the slopes for latency across the first few positions, the slope is substantially smaller over SP 4 and 5 in the *inflected* condition. This deviant result is not necessarily problematic for the notion of serial search from SP 4 to SP 5 in grouped lists. The relative short latency at SP 5 can be explained by assuming that in a number of trials, direct access via the recency cue has caused fast retrieval. Hence, the slope between SP 4 and 5 overestimates the rate of search. Retrieval of the fourth and fifth item via the recency cue can also be witnessed in the monotone condition. Positional cueing theory can also explain the shorter RTs as SP 5 and even at SP 4 in the second half of the experiment. It suggests that, as a result of practice, there is an increasing number of occasions on which retrieval relies on the remote associations of the recency cue, which provides fast direct access. This also explains why there is hardly any effect of sessions on the remaining SPs.

It may be concluded that the experimental task successfully prevented chunking of individual items in the inflected condition, in the sense that these items would have a common memorial representation. It seems rather implausible to assume that chunking would cause an advantage restricted to particular serial positions, as observed in the present experiment. In addition, the data are in conflict with the notion of a uniform decoding operation for both chunks (cf. Johnson 1978), since there are substantial differences in the course of mean RT across SPs within each group.

The present results only partially support Estes' model on the perturbations of order information in primary memory. It is in good agreement with this model that effects on RT and error rate are both in the same direction. As argued, both recall latency and errors may reflect loss of order information, since the quality of the memory representations of the individual items is affected by perturbations of the order of the constituent features. Consequently, perturbations increase the duration of the identification process at the time of recall.

With respect to both latency and accuracy, the bow-shaped serial position curve in the monotone condition and its asymmetry in favor of the most recent items are in accord with perturbation theory. These features are also observed in the inflected condition: within each half of the list, RT and accuracy tend to be bow-shaped functions of SP. In addition, the results for the second half of the grouped lists are superior to those for the first half, which is in accord with the prediction that recall deteriorates as a function of retention interval.

The absence of any increase of reaction time at SP 1 and SP 6 in grouped lists as compared to ungrouped lists indicates that there is no general prolonging effect on RT as a result of an extra hierarchical level in the coded representation of grouped lists. Such an effect would have suggested decoding of a hierarchical structure. Yet, the absence of such an effect merely excludes the possibility that the differential effects of perturbations across serial positions are obscured by general decoding effects. Hence, perturbation theory predicts that reaction time in grouped lists conforms to the ordinal relations among serial positions, as summarized in fig. 1.

The latency data in the inflected condition only partly support the predictions of the Estes model. Confirmatory evidence is found in the bow-shaped curve across SPs 4, 5 and 6. Performance on that three-item sequence (ABC) confirms to the predicted pattern C-A-B. The large reduction of RT at SP 4, as compared to the monotone condition, is in accord with the notion that items at group boundaries suffer less from perturbations. The model also explains the reduction of RT at SP 5 as a consequence of less perturbations for a shorter sequence of items. However, there are no similar effects for the first group of three items. In fact, the results do not show the predicted C-A-B pattern. The model predicts for the first group the shortest latency at SP 3. Instead, the third item consistently produces long latencies, at the same level as SP 2. This lack of advantage of SP 3 over SP 2 is problematic, since the boundary item at SP 3 is supposed to suffer merely from unidirectional perturbations. Furthermore, the Estes model would expect a reduction of RT at SP 2 relative to the monotone condition, due to a shorter sequence. This reduction should be of about the same size as observed at SP 5. Finally, performance at SP 4 is by far superior than at SP 3, which is contrary to the prediction that these positions will have about equal recall latency (see fig. 1).

The present results also seem to exclude the view that beneficial effects of grouping on short-term retention are caused by improved distinctiveness of the stored memory representations, as a result of voice inflection. Such a view would expect the major effects to occur at SP 3 and SP 6, as these items are differently voiced. Instead, the predominant effect is found at SP 4. Moreover, this view cannot accommodate the effect at SP 5. A somewhat related view could be based on the contention that during acquisition, voice inflection causes attentional control to be differently distributed over the items, causing different degrees of quality or availability of the memory representations (e.g., Murdock 1972). However, such a view would expect that a benefit derived from stressing one item would imply at least some cost for other items. Instead, recall latencies at SP 1, 2 and 6 are not affected. Thus, there are neither costs at SP 1 and SP 2 as a consequence of voice inflection, nor is there an additional gain at SP 6. Instead, SP 5 is the beneficiary. Hence, it appears that the effect is not due to a better encoding or storage of particular items.

In summary, positional cueing theory appears to accommodate the present findings in considerable detail, whereas Estes' perturbation model fails on some essential issues. In particular, the effects of intonation mode on recall latency in the first part of the list pose considerable problems. Grouping appears to create additional pathways for retrieval rather than changing the storage mode.

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CHAPTER 3

TEMPORAL ASPECTS OF RETRIEVAL IN SHORT-TERM SERIAL RETENTION

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TEMPORAL ASPECTS OF RETRIEVAL IN SHORT-TERM SERIAL RETENTION *

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In three experiments, temporal properties of memory retrieval are studied. Latency of positionally probed recall of a single item is measured as a function of its serial position (SP) in a serial list. The requested SP is indicated by a positional probe, presented immediately after the list. For two organizational structures of the list (i.e., grouped vs. ungrouped lists) the experiments study the effects of precueing the probe position briefly before probe presentation, the cue signal indicating the SPs relevant for recall. The problem of confounded effects on latency of requested SP and of probe-signal location is also investigated. A bow-shaped SP-curve is found for ungrouped lists; precueing reduces RT but does not affect the bowed shape. This argues against selective confounding effects of spatial probe position and also suggests that precueing preactivates memory access. Grouping the items into two sublists eliminates precueing effects for items around the group boundary. Furthermore, precueing is detrimental when SPs at opposite ends of the list are precued. This suggests that the available points of memory access can only be utilized one at a time, so that precueing is not beneficial when the item cannot be reached via the preactivated point. Although the notion of single access to memory is in accord with both positional cueing theory and non-associative hierarchical theories (e.g., Estes 1972), various details of the results are in favor of the first type of explanation.

The aim of this paper is to study some temporal properties of retrieval in short-term retention, by employing a positional probe technique. In positionally probed recall, a probe is presented immediately after presentation of a list of items. The probe indicates one particular serial position (SP) and the subject's task is to reproduce the item presented at the probed SP as quickly as possible. The main measure is speed of correct recall as a function of SP. This method has the advantage over the traditional measure of proportion of correct recall, in that it tests the course of successful memory retrieval rather than of forgetting (e.g., Murdock 1961; Moss and Sharac 1970; Sanders and Willemsen 1978).

It is one purpose of this study to investigate a possible methodological criticism against the use of the positional probe technique (experiment 1), namely that the measure confounds effects of probe localization and memory retrieval. For this purpose, the experiments investigated the effects of precueing the probe by presenting partial advance information. Secondly, this study uses the precueing technique to investigate some temporal properties of the retrieval process (experiment 2 and 3).

Methodological objective

In the positional probe technique, recall latency is measured from the onset of the positional probe and is considered to reflect retrieval time. This means that RT should not be seriously affected – and certainly not selectively across serial positions – by perceptual processes involved in the identification of the probe. A positional probe has usually consisted of one visual signal out of a horizontal array of lights. Within this array, the utmost left light refers to the first SP, the next light to the second SP, etc. Hence, a potential problem for the positional probe technique follows from the well known fact that choice RT is substantially affected by the spatial position of the action signal as well as by the size of the array (Welford 1973).

The present study attempts to deconfound the effects of spatial probe position and of SP of the to-be-recalled (TBR) item, by presenting partial advance information (PAI) about the position of the probe signal. PAI is presented briefly in advance of the probe and consists of a cue signal indicating a specific subset of the probe locations. The probe is exclusively drawn from that subset, and, hence, the cue signal reduces uncertainty about the position of the forthcoming probe. Leonard (1958) has found in a six-choice reaction task that whenever PAI reduced the number of alternatives from six to three, RT was reduced to the level of a three-choice reaction task. That reduction was obtained when PAI preceded the action signal by at least 300 msec. Using a 300 msec interval, Hendrikx (in prep.) found that six-choice

RT can be reduced to the level of two-choice RT if PAI reduces the relevant signal-alternatives to a subset of two. Furthermore, he showed that PAI eliminated the effect of the spatial position of the action signal. Hence, PAI appears a suitable technique to eliminate effects of spatial probe position on recall latency.

Theoretical objective

It is conceivable that precueing preactivates an initial stage of memory retrieval during the interval separating cue and probe and, thus, it could be used as a chronometric tool to reveal some properties of memory retrieval. Recently, Sanders (1975) proposed a *positional cueing theory* of memory retrieval, in which direct access is viewed as the first stage of the retrieval process. A positional primacy cue gives access to the first item of a serial list, which is followed by a serial search for subsequent items; The terminal items are directly accessed *via* a positional recency cue. This theory can easily explain results such as the well-known bow-shaped form of serial position curves for errors and for recall latency (Sanders and Willemsen 1979; Hendrikx 1984). In terms of positional cueing theory, a cue signal may, in advance of probe presentation, preactivate direct access, as the first stage of retrieval. The choice of the point of access would depend on which of the positional cues provides a pathway to the precued serial positions. Of course, preactivation would not necessarily be restricted to direct access; With a longer cue-probe interval, precueing could also proceed to serial search for the precued items. The rate of serial search has been estimated at 200 msec/item (Sanders and Willemsen 1978; Hendrikx 1984). Hence, a precueing interval of 300 msec, as employed in the present experiments, seems small enough to expect preactivation to be restricted to direct access.

As a first test of the question whether precueing preactivates direct access, grouped lists were used. Grouping of successively presented items is known to considerably improve recall (e.g. Bower and Springston 1970; Laughery and Spector 1972; Johnson 1978). Positional cueing theory assumes that grouping into two sublists creates additional positional cues at the boundary between the groups: an auxiliary recency cue for the last item of the first group and an auxiliary primacy cue for the first item of the second group. In support of positional cueing theory Hendrikx (1984) found that instructions to subjectively group the items improved speed and accuracy of positionally probed recall, but only of those items that can be retrieved *via* the auxiliary positional cues.

Hence, if precueing preactivates memory retrieval, the precueing effects are expected to interact with the effects of grouping, for the simple reason that the possible points of direct access are dictated by the grouping structure. On the other hand, if precueing only influences probe localization, the precueing effect should be independent of grouping.

In experiment 1, the grouping factor was therefore explicitly controlled by instructing the subjects either to vocalize the items of a six-item list during presentation in a *monotone* way or, alternatively, to read the third and sixth item with an *inflected* voice. Thus, subjects were encouraged to either treat all items as a single group or as two smaller groups.

As the results of experiment 1 confirmed that precueing facilitates retrieval, experiments 2 and 3 further investigated some properties of direct memory access.

Experiment 1

Method

Subjects and tasks

Nine male and eleven female students of Tilburg University, beteen 19 and 28 years of age, participated in the experiment. They were randomly assigned to either the "*monotone*" or to the "*inflected*" intonation group ($n = 10$ for each group). *S*s were paid and had no previous experience in memory experiments.

In a trial, six consonants were presented in succession at a rate of 2 items/sec, randomly chosen without replacement from the subset F, J, K, L, N, P, R, T, Z. The last consonant was followed, after a 500 msec interval, by either a control signal (in the *control condition*) or by one of three possible cue signals (in the *cue-condition*). Either signal lasted for 2.8 sec. The control signal consisted of a horizontal array of six lights, whereas the cue signal consisted of a subset of two of these lights, in positions (from left to right) 1 and 2, or 3 and 4, or 5 and 6. These cue configurations are respectively labeled "12", "34", and "56". The cue lights provided partial advance information about the location of the forthcoming probe signal which was presented 300 msec later. The probe consisted of a single light that occurred at one of six possible positions in a horizontal array of six luminous dots. The row of dots was positioned slightly below the array containing the cue or the control signal. The location of the probe in the dot row indicated the serial position of the TBR item, i.e., position 1 through 6 from left to right. The *S*s were instructed to vocally recall the probed item as quickly and accurately as possible upon presentation of the probe. RT was the interval between the onset of the probe and the initiation of the vocal response.

The probe always occurred at a random position in the dot row, but with the restriction that, in the cue-condition, the probe position coincided with one of the cue-light positions. The six positions of the probe were equiprobable and so were the three possible positions of the cue-signal. For a given cue-signal, the probe occurred in either of the cued SPs with a probability of 0.50. The probe lasted for 2.5 sec and it was displayed at twice the intensity of the other signals.

In the *monotone* intonation condition, *S*s were instructed to vocalize the items during presentation in a monotone way, i.e., without stressing a letter or changing voice inflection. In the *inflected* intonation condition, *S*s were instructed to emphasize the third and the sixth item differently by changing voice inflection. Intonation mode was a between-*S*s variable, because of dangers of asymmetric transfer (Poulton 1973). Either way of intonation was well practiced in advance and continually monitored. In both intonation modes, *S*s practiced to adopt a rate of speech similar to the rate of letter-presentation.

In the *control* condition, *S*s were told that in all trials a control signal would be presented in advance of the probe. The control signal should be regarded as a temporal warning signal, as it was always presented 300 msec in advance of the probe. In the *cue*-condition one of the various cue signals was randomly presented instead of the control signal. *S*s were instructed to attempt to use this advance information in order to improve their speed of recall.

Apparatus and display

The *S* was seated in a dimly lit, sound attenuating room and faced a computer-controlled scope (Digital GT-40), at a distance of about 130 cm. Trial onset was signalled by a 500 msec tone of 2900 Hz (65 dB). During the entire trial, seven luminous dots (1 mm in diameter) were presented. One dot served as a fixation point and was located 17 mm above the centre of the scope. Six dots appeared in a horizontal row, at equidistant intervals (11 mm), at 35 mm symmetrically below the fixation point. The six dots signified, from left to right, the serial positions 1 through 6 of the TBR items. One sec after the tone, 6 capital letters were presented in sequence (2/sec) in the area surrounding the fixation point (height 22 mm, width 11 mm). Each letter was presented for 100 msec, but it remained visible for about 300 msec, due to the phosphorescence of the scope. In the control condition, the last letter was followed after 500 msec by a control signal, consisting of six lights (height 4 mm, width 2 mm), positioned 8 mm above the permanently visible row of dots. Thus, there were six vertical pairs of one light and one dot. The probe consisted of a single light (2 × 4 mm), at one of the six positions in the row of dots. After the simultaneous offset of all signals, a blank interval of 4 sec preceded the warning signal of the next trial.

Procedure and design

Intonation (i.e., grouping-) conditions were assigned to separate groups of *S*s, while all *S*s participated in the cue- and the control condition. Each *S* participated in four experimental sessions, preceded by a practice session. In the practice session, *S*s practiced a 6-item memory-span task with ordered written recall. Stimulus materials and presentation procedures for this practice task were grossly identical to those of the experimental task. In addition, there were 60 practice-trials on the control and cue-condition of the experimental task. Only in the practice session, *S*s recieved knowledge of results on speed and accuracy. The experimental sessions lasted 30 min and were separated by 30-min breaks. Each session consisted of two trialblocks, separated by a 2-min break. A block consisted of 60 trials, preceded by 3 warm-up trials. One block was devoted to the control condition, the other to the cue-condition. The blocks for the cue- and the control condition were counterbalanced over sessions. In all conditions, the same sequences of letter-lists were employed.

Two different sequences of 60 six-letter lists were composed. Within a list, there were neither repetitions of letters, nor did any letter occupy the same SP in any two successive lists. For each sequence of 60 lists, the SP at which the probe signal occurred was specified for each list in such a way that (a) each SP was probed 10 times, (b) a position was not probed more than twice in succession, (c) the same consonant was not requested for recall more than twice in succession, (d) with some minor deviations, each letter from the set of consonants was probed once at each SP. In order to counterbalance possible sequential within-list effects, a mirrored variant of each of the two sequences was also employed. In the mirrored variant, the order of the letters in each list, and the order of the lists, was inverted. Furthermore, the SP of the probe in each inverted list was mirrored relative to the middle of the list. Thus, the probe kept pointing towards the same consonant as in the original list. Each list-sequence and its mirrored variant were used once in each of the control and cue-condition for each *S*. This rendered for each of the cue- and the control condition a total of 40 RT measurements at each SP per *S*, divided about equally over the nine letter-alternatives. This minimized possible artifacts in the onset of the RT-interval, resulting from differences in the pronunciation of the consonants.

Results

Fig. 1 presents the mean RTs of correct responses and percentages of recall errors, as a function of SP, for each intonation mode and precueing condition (cue vs. control). The data are averaged over *S*s. Comparison between the first and second half of the experiment (left vs. right panel) shows the results to be very stable. Fig. 1 also reveals that, while the error curves of the cue- and the control condition are similar, there are clearcut effects of precueing on mean RTs. The effects of intonation mode will only be briefly mentioned, since they are discussed elsewhere (Hendrikx 1984). In short, the effects of grouping are restricted to the middle-of-the-list positions with regard to both speed and accuracy.

In the monotone condition, the familiar bow-shaped SP-curve is observed in both the cue- and control condition. Furthermore, there is a fairly general precueing effect, consisting of a substantial reduction of mean RTs. This contrasts with results of the inflected condition where the SP-curves have a bimodal shape and where precueing only affects RT at SP 1, 2 and 6.

A $2 \times 2 \times 2 \times 6$ ANOVA was performed on individual means of RT in correct trials, with intonation mode as the between-*S*s factor and with the following within-*S* factors: Sessions (1 and 2 vs. 3 and 4), Precueing (control vs. cue-condition) and SP (1–6). Results are presented in the left part of table 1. All main effects were significant, as well as two of the first-order interactions: Intonation × SP and Precueing × SP that were part of the significant second-order interaction Intonation × Precueing × SP. All

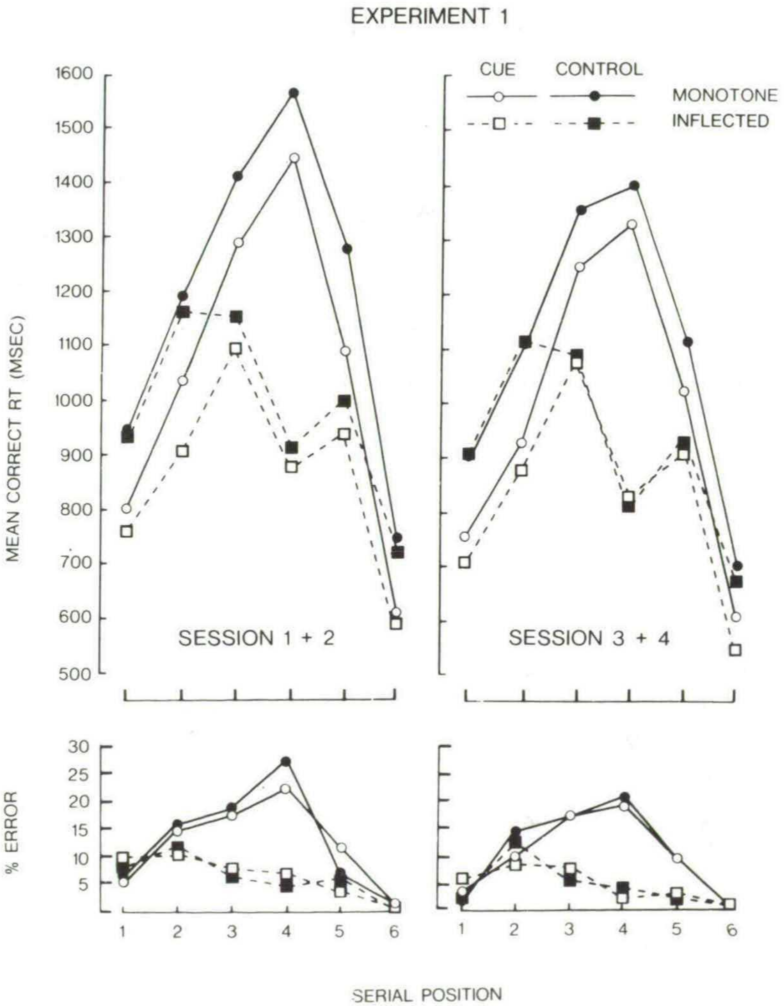

Fig. 1. Mean correct reaction times and mean percentages of recall errors as a function of serial position of the to-be-recalled item, in experiment 1. Control condition: filled symbols; cue-condition: open symbols. Monotone condition: circles; Inflected condition: squares. For each intonation mode the data are averaged over 10 subjects.

significant effects were stable across sessions, indicating no strategy shifts across sessions. Further analyses were thus conducted on mean RTs, averaged over all sessions.

As apparent from fig. 1, the significant second-order interaction Intonation × Precueing × SP reflects the finding that in the inflected condition, there is no precueing-effect at middle-of-the-list positions, whereas it is clearly observed in all other cases. As an additional check on this result, two separate $2 \times 2 \times 3$ ANOVA's were performed on individual means of RT. In the first ANOVA, SP 1, 2 and 6 were involved, while the second one analyzed SP 3, 4, and 5. Both ANOVA's had Intonation, Precueing and SP as variables. The results are presented in, respectively, the middle and the right panel of table 1.

In summary, the ANOVA on SP 1, 2 and 6 indicated significant main effects of Precueing and of SP, but not of Intonation. In contrast, in the ANOVA on SP 3, 4 and 5, all three main effects were significant. Most importantly, the latter analysis showed a highly significant interaction of Intonation × Precueing for the middle of the list, which confirms that the beneficial effect of precueing is only present in the monotone condition. Again, this is in contrast with the ANOVA on SP 1, 2 and 6, which showed only a marginal significant interaction of Intonation × Precueing ($p = 0.04$), due to a somewhat *larger* effect of Precueing in the inflected condition, in particular at SP 2.

Another interesting contrast between the two ANOVA's involves the Intonation × SP interaction, which is only significant across SP 3, 4 and 5. This is due to the

Table 1
Analyses of Variance in experiment 1.

Source	All serial positions		Serial positions				
			1–2–6			3–4–5	
	df	*F*		*df*	*F*	*df*	*F*
Intonation (A)	1,18	15.2 [b]	A	1,18	0.6	1,18	24.5 [b]
Precueing (B)	1,18	188.4 [b]	B	1,18	243.3 [b]	1,18	37.5 [b]
Serial Pos. (C)	5,90	58.2 [b]	C	2,36	111.2 [b]	2,36	9.8 [b]
Sessions (D)	1,18	21.3 [b]	–	–	–	–	–
A×B	1,18	1.5	A×B	1,18	4.6 [a]	1,18	13.2 [b]
A×C	5,90	14.7 [b]	A×C	2,36	0.1	2,36	13.3 [b]
B×C	5,90	6.3 [b]	B×C	2,36	10.3 [b]	2,36	0.4
A×D	1,18	1.1	–	–	–	–	–
B×D	1,18	3.2	–	–	–	–	–
C×D	5,90	2.0	–	–	–	–	–
A×B×C	5,90	2.7 [a]	A×B×C	2,36	1.5	2,36	0.1
A×B×D	1,18	0.1	–	–	–	–	–
A×C×D	5,90	0.9	–	–	–	–	–
B×C×D	5,90	0.9	–	–	–	–	–
A×B×C×D	5,90	0.4	–	–	–	–	–

[a] $p < 0.05$ [b] $p < 0.01$

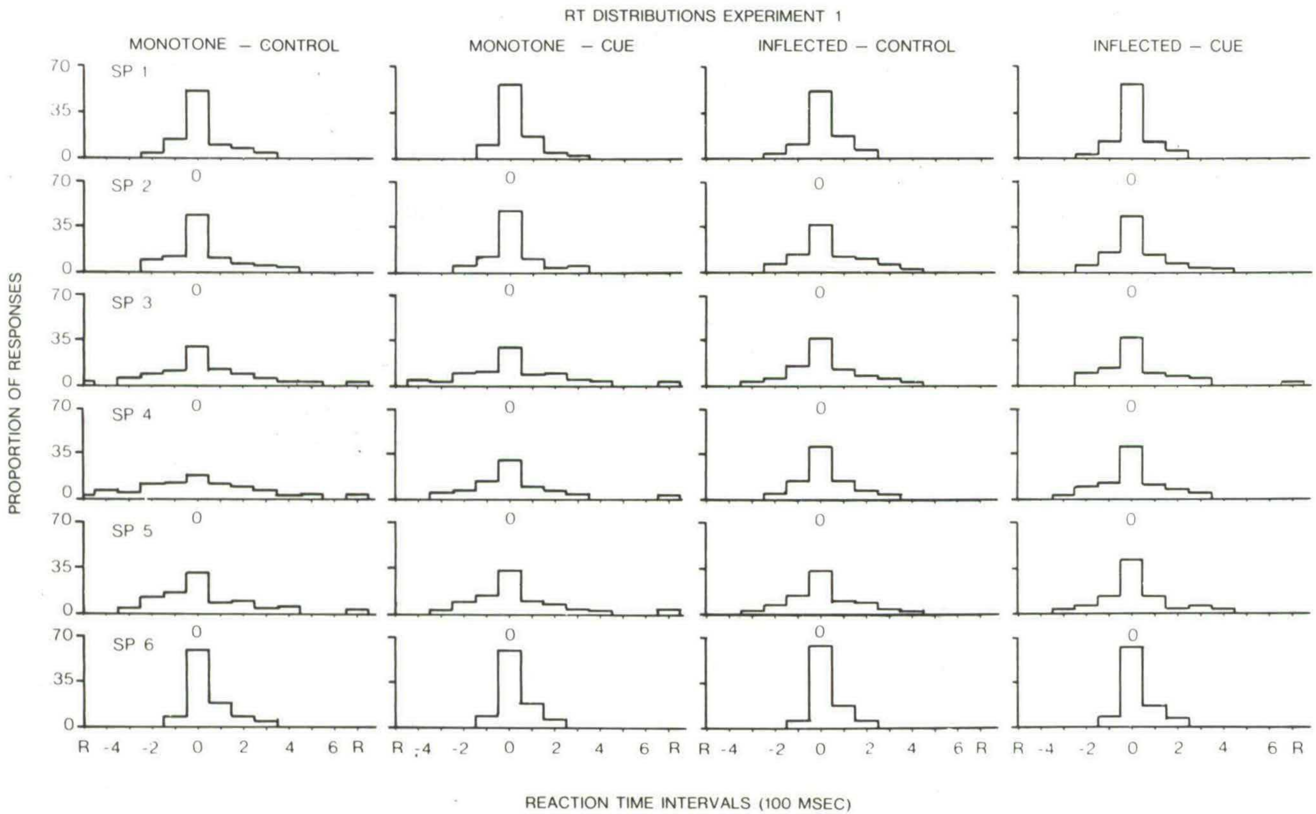

Fig. 2. Histograms of correct reaction times (RT) in each experimental condition (columns) of experiment 1 and for each serial position (SP, in rows). Within each RT-interval, the data are summed over single trialblocks. Each individual mean RT of a block is set to the center of the middle RT-interval, marked "0". Interval widths are 100 msec. Observations exceeding the range of 11 intervals are pooled in the intervals marked "R", at either side.

shape-inversion of the SP-curve in the inflected condition. The absence of higher order interactions confirms that this inversion is independent of precueing.

Fig. 2 pictures the variability of RT for each SP and condition, by way of histograms based on the sum of individual RT-distributions of correct recall in each trialblock. The mean of each contributing distribution is set equal to the midpoint of the histogram. Hence, the histograms do not reflect variability across trialblocks or *S*s, but rather variability of individual data within trialblocks. There is substantial agreement among conditions in the change of the distributions as a function of SP. Generally, there is a gradual increase of variability across the first four items, and a decrease across the two last SPs, particularly in the monotone control condition. Furthermore, the positive skewness observed at SP 1 and SP 6 diminuishes for middle-of-the-list positions. Comparisons among conditions indicate obvious differences in "spread" for middle-of-the-list positions, in contrast to SP 1 and SP 6, where there is a remarkable similarity among conditions. In particular, long RTs at middle positions are more frequently observed in the monotone condition. Furthermore, precueing causes a substantial reduction of RT variability at SP 4 in the monotone condition.

Discussion

Precueing does not appear to affect the *shape* of the SP-curve in the monotone condition. This suggests that probe localization does not selectively affect certain spatial positions. Furthermore, the *size* of the precueing effect in the monotone condition is large in comparison with the reduction in a six-choice reaction task (Hendrikx in prep.). There, precueing virtually eliminated effects of spatial position of the action signal, suggesting already that precueing entirely eliminates spatial effects. Hence, one may safely conclude that there are no substantial perceptual confounding effects of spatial probe position on recall latency . The shape of the SP-curve for latency can therefore be ascribed to memory factors.

Two features of the results clearly suggest that precueing has indeed an effect on memory retrieval. One feature concerns the substantial size of the precueing effect in the monotone condition, which is considerably larger than precueing effects in choice reactions (Hendrikx in prep.). Therefore, the present precueing effects can hardly result from mere facilitation of processes occurring *prior* to retrieval, such as perceptual probe processing.

Secondly, the relatively constant effect of precueing across SPs in the monotone condition suggests that precueing affects a stage of the retrieval process that is common to *all* SPs. As a possible candidate, positional cueing theory would propose that the process of direct memory access is preactivated, at a serial position that is tagged with one of the positional cues. Direct access *via* the primacy cue might become preactivated by precueing positions 1 and 2 or positions 3 and 4, while precueing the two last serial positions would preactivate direct access *via* the recency cue. In principle, the next retrieval stage, i.e., serial memory search, could also be preactivated. In that case, the effect of precueing should decline across SPs in the primacy part of the list. This is clearly not found with the present 300 msec interval but it was observed for intervals of

900 msec in an unpublished study by this author. The notion of preactivated direct access is also consistent with the similar size of the precueing effects at the beginning and the end of the list. Apparently, the primacy and the recency cue can serve equally well as a point of preactivation.

Other evidence in support of preactivation of direct memory access by precueing concerns the interaction among the effects of precueing, intonation mode and SP. Evidently, the effects of precueing at middle-of-the-list positions depend on intonation mode as a list-acquisition variable. This defies an explanation of precueing which leaves memory retrieval unaffected. Yet, the advantage of precueing is eliminated rather than promoted in the inflected condition, suggesting that, in some way, direct access to these items cannot be accomplished.

The present solution proposes that precueing may create a conflict between possible points of direct access, of which only one can be preactivated. More specifically, the absence of precueing effects at SP 3, 4 and 5 in the inflected condition is caused by a conflict between two such points of access. As argued by Hendrikx (1984), grouping creates two additional positional cues that allow direct access to SP 3 or to SP 4, thereby eliminating the necessity of conducting a serial search for these items. However, this advantage may obstruct the precueing advantage. Assuming that a control mechanism for memory retrieval allows only a single point of direct access at a time, it follows that precueing SP 3 and SP 4 jointly poses a dilemma as to which item to access. This may explain why these positions doe not show a beneficial effect of precueing. Of course, this explanation is a *post-hoc* extension of positional cueing theory and, hence, in need of empirical verification, which will be pursued in experiments 2 and 3. Yet, this interpretation is in line with the fact that intonation mode does not influence the effect of precueing on the two first items and the terminal item, as retrieval of these items remains under control of the original positional cues.

The notion of serial search for the middle-of-the-list positions is also supported by the waxing and waning of *RT variability* across SPs in the monotone control condition (see fig. 2). The RT histograms can be taken to represent the execution times of all retrieval stages. The time of direct access, then, is reflected at SP 1, while for SP 2, 3 and 4, the histograms reflect the sum of, respectively, one, two or three search-time distributions, as each step of the search adds a certain amount of variability. Support for this view is found in the decreasing skewness of the distributions across the first four SPs. For later items in the list, RT includes a greater number of independent search times, so that occasional extreme values tend to be averaged out. A second notorious feature is the relative small variability at SP 3 and SP 4 in the inflected condition. It confirms that, when serial search for these items is avoided, there is no build-up of variability as in the monotone condition.

With respect to *recall errors*, all experimental conditions show a striking similarity between the course of the SP-curves for speed and accuracy, suggesting that the effects of SP on mean RT are not distorted by speed-accuracy trade-off. Similarly, effects of grouping suggest that additional retrieval cues decrease both latency and accuracy. However, precueing has hardly any effect on accuracy. This is consistent with the above proposed explanation, in the sense that accuracy depends on the *availability* of an extra retrieval cue, whereas it does not matter whether that cue is used for direct access before or after probe presentation.

Experiments 2 and 3

Experiments 2 and 3 were conducted to test the single access explanation proposed for the interactive effects of intonation and precueing. It was predicted that preactivation is only beneficial to recall when the precued serial positions can *all* be retrieved through a single point of direct access.

Experiment 2 tested this prediction within the context of the grouping effect, as induced by intonation mode. It was reasoned that, if a precued item is positioned at a group boundary, the question whether or not the item benefits from precueing depends on whether *all* of the precued SPs are located at the same side of the group boundary. In that case, all SPs will be accessible *via* a single positional cue. Hence, when a six-item list is grouped into two equal sublists, it follows that recall speed at SP 3 or SP 4 will benefit from precueing as long as only positions *within* either the first or the second part of the list are precued.

Experiment 3 again tested single direct access, by looking at the effects of simultaneous precueing of positions at opposite ends of a list. It was reasoned that only one of these juxtaposed positions can benefit from preactivation of direct access, either *via* the primacy or *via* the recency cue. Hence, for juxtaposed positions there will be either no precueing effect at all (on account of the dilemma concerning the direction of access) or, alternatively, there will be a beneficial effect on one of the positions and at the same time an adverse effect on the other precued position. The last type of result would indicate a bias in direct access to a particular part of the list.

Experiment 2

Experiment 2 differed only from the previous in that a number of additional cue-configurations were employed, i.e., the cue-configurations "23", "123", both pointing to positions within the first sublist, and the cue-configurations "45" and "456", both pointing to positions within the second sublist. (The numerals indicate the spatial positions of the cue-lights.) Again, effects of precueing were assessed in an ungrouped (monotone) and a grouped (inflected) condition.

Method

Five male and eleven female students of Tilburg University, between 18 and 39 years of age, participated in the experiment. They were randomly assigned to either the monotone group or to the inflected group ($n = 8$ for each group). *S*s participated either to fulfill a course requirement or else were paid for their services. *S*s had no previous experience with experiments in short-term retention.

The procedure, design and the tasks in the cue- and the control condition were essentially the same as in experiment 1. The main difference with the previous experiment was the greater number of different cue-configurations.

In the cue-condition, seven different cue-configurations occurred randomly in a block of trials. As in experiment 1, the cues provided advance information about the location of the forthcoming probe-signal. The cue-configurations always consisted of either two or three cue-lights, presented at adjacent SPs. Three of these configurations had also been used in experiment 1, i.e., cue "12", cue "34", and cue "56" (the digits referring to the cued SPs). For convenience, these three configurations will be referred to as cue-condition 12–34–56. The four additional cue-configurations were constructed so that all of the precued SPs were located either within the first or within the second half of the list. These configurations were labeled "23", "45", "123", and "456". The configurations "23" and "45" will be referred to as cue-condition 23–45, and the configurations "123" and "456" will be termed cue-condition 123–456.

In each block of trials, a sequence of 64 lists of six letters was presented. Within a trialblock of the cue-condition, each of the seven cue-configurations was pseudo-randomly presented. For each cue, the probe signal occurred four times at each cued SP. Thus, each cue consisting of two lights occurred eight times within a block and those consisting of three cue-lights occurred twelve times. The probe could only occur at one of the positions indicated by the cue-lights. Consequently, SP 1 and 6 were each probed eight times within each trialblock, whereas the remaining SPs were each probed twelve times. In each sequence of 64 lists, the four probed letters at a given SP and under a certain cue-configuration, were all different. This diversity was also maintained across trialblocks, in order to minimize differential effects of letter pronunciation on vocal RT. The control condition was the same as in experiment 1.

The same sequences of probed letter-lists were used as in experiment 1, so that letter- and order-effects within and between lists were balanced. However, three lists were added to each sequence to accommodate blocks of 64 experimental trials. In the two intonation modes, the same sequences of probed lists and cue-signals were used. This was also true for the control and the cue-condition.

Each *S* served in two 30-min sessions, separated by a 30-min pause and in a preliminary practice session. All experimental sessions consisted of two blocks of 64 trials, one for the cue- and one for the control condition. *S*s in the inflected condition did an additional session about seven days later, to obtain more data in the cue-condition. That session was entirely devoted to the cue-conditions. It was preceded by a practice session devoted to the cue- and the control condition.

Results

Fig. 3 presents mean RTs of correctly recalled consonants as a function of SP, for both intonation modes and precueing conditions (control vs. cue). The data are averaged over *S*s and based on two sessions. The data of one *S* in the monotone group were discarded because the intonation instruction was not sufficiently obeyed. The SP-curves for errors were very similar to those in comparable conditions of experiment 1. Within intonation conditions, there were only minor differences in error rates between the cue- and control condition.

Monotone intonation mode

In the control condition, the results on mean RTs replicate the bow-shaped SP-curve as found in experiment 1. In cue-condition 12–34–56, mean RTs are substantially reduced over all SPs relative to the control condition, with the exception of an anomalous absence of an effect at SP 3. An ANOVA on individual mean RTs, with variables SP (1–6) and Precueing (control condition vs. cue-condition 12–34–56 vs. cue-condition 123–456), revealed significant main effects of Precueing ($F(2, 12) = 4.5$, $p = 0.03$), and SP ($F(5,30) = 27.5$, $p < 0.001$). There was no significant interaction of SP × Precueing, indicating stable effects of precueing across SPs. A *post-hoc* simultaneous test procedure among the three levels of Precueing indicated that either cue-condition was significantly smaller than the control condition.

Essentially the same result was obtained with "23" and "45". A 2 × 4 ANOVA on individual mean RTs with variables Precueing (control vs. cue-condition 23–45) and SP (restricted to the range 2–5) showed significant main effects for Precueing ($F(1,6) =$

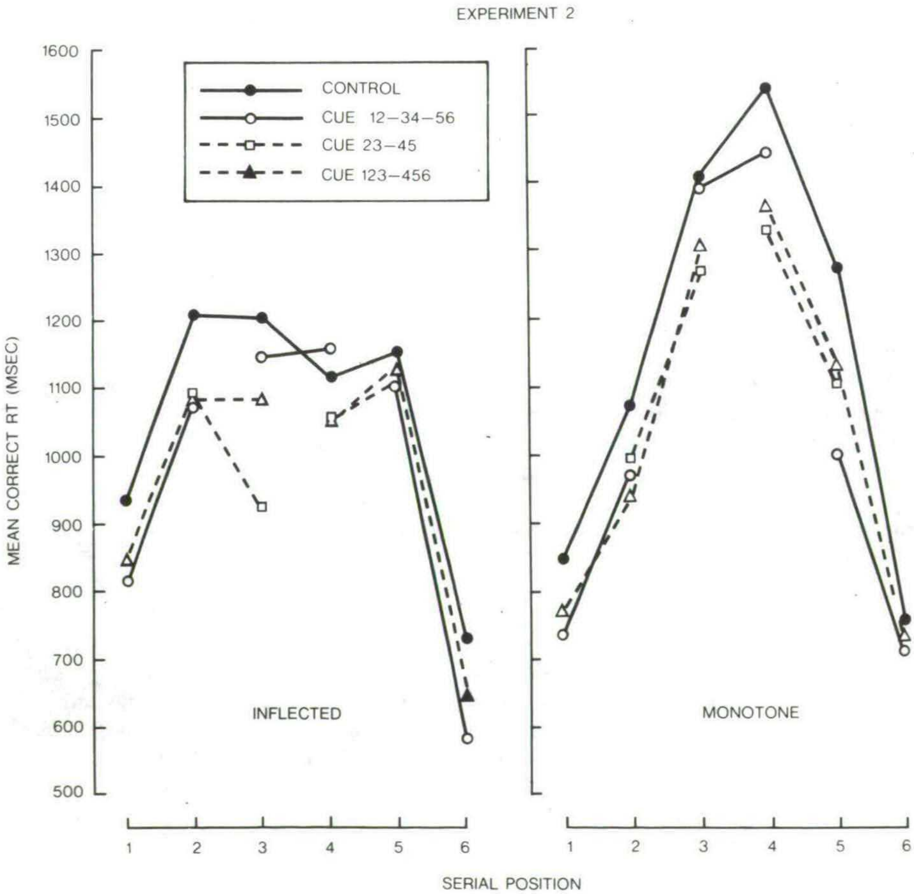

Fig. 3. Mean correct reaction times as a function of serial position in experiment 2, based on two sessions. Left panel: inflected intonation mode. Right panel: monotone intonation mode. Open circles depict the various cue-conditions. Simultaneously cued serial positions are interconnected.

7.9, $p = 0.03$) and for SP ($F(3,18) = 7.5$, $p < 0.01$). The interaction of Precueing × SP was not significant.

Inflected intonation mode

Fig. 3 shows that in the inflected control condition mean RTs are reduced for middle-of-the-list positions. The effect of precueing in cue-condition 12–34–56 is restricted to SP 1, SP 2 and SP 6. Both results replicate the grouping-effects observed in experiment 1. An ANOVA was performed on individual mean RTs in the control condition and in cue-condition 12–34–56, with Precueing and SP as variables. The main effect of SP was significant ($F(5,35) = 36.5$, $p < 0.001$), whereas the main effect of Precueing barely reached significance ($F(1,7) = 4.7$, $p = 0.06$). However, there was a significant interaction between the effects of Precueing and SP ($F(5,35) = 3.3$, $p = 0.02$), reflecting the small effect of Precueing at SP 3 through SP 5, relative to the effects at the other SPs.

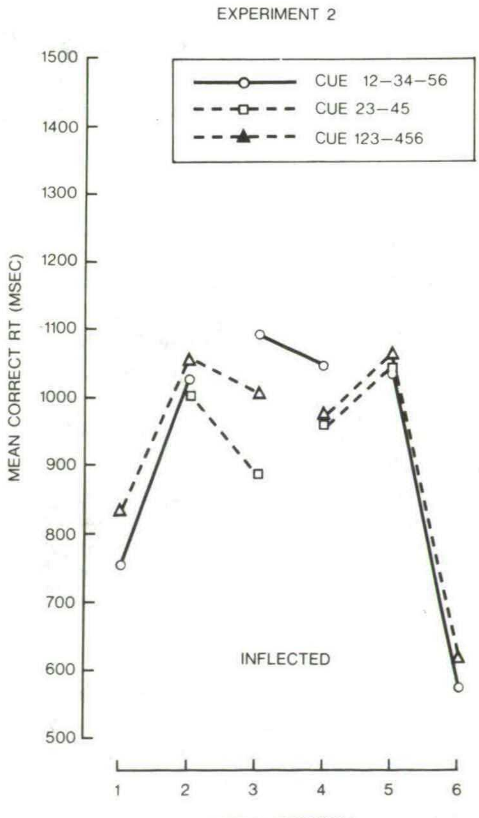

Fig. 4. Mean correct reaction times as a function of serial position, in the cue-conditions and the inflected intonation mode, in experiment 2. Means are based on three sessions.

A similar ANOVA, with variables SP and Precueing (control vs. cue-condition 123–456) showed significant main effects of Precueing ($F(1,7) = 8.8$, $p = 0.02$), and of SP ($F(5,35) = 25$, $p < 0.001$), but no significant interaction between these effects. These results reflect that Precueing effects in condition 123–456, are stable across SPs.

An ANOVA on individual mean RTs was performed with variables Precueing (control vs. cue-condition 23–45) and SP (restricted to the range 2–5). The main effect of Precueing was significant ($F(1,7) = 19$, $p < 0.01$). There was no significant main effect of SP. However, the interaction between the effects of SP and Precueing was significant ($F(3,21) = 4.9$, $p = 0.01$).

Fig. 4 presents individual mean RTs of the three cue-conditions, computed over three sessions. Comparisons among cue-conditions show virtually equal mean RTs at SP 2 and SP 5. However, at SP 3 and SP 4, there is a substantial advantage for conditions 23–45, as well as for condition 123–456, over condition 12–34–56. This observation was substantiated by an ANOVA performed on individual mean RTs, calculated over three sessions, with variables Precueing (cue-conditions 12–34–56 vs. 23–45 vs. 123–456) and SP (restricted to the range 2–5). There was a significant main effect of Precueing ($F(2,14) = 8.2$, $p < 0.01$). The main effect of SP was not significant. Most importantly, there was a significant interaction between effects of SP and Precueing ($F(6,42) = 3.1$, $p = 0.01$). The results of experiment 2 will be discussed jointly with those of experiment 3.

Experiment 3

This experiment aimed at testing the prediction that simultaneous precueing of an "early" and a "late" SP (with respect to the presentation order), will either annihilate the effect of precueing or lead to a beneficial effect at only *one* of these SPs. In the latter case, the effect of precueing is expected to be negative at the other SP, in the sense that recall speed will increase relative to the control condition. As argued, this is predicted because SPs at opposite ends of the list must by accessed *via* different positional cues and these positions cannot both benefit from preactivation of direct access.

To test this hypothesis, a number of cue-configurations were employed, some of which concerned adjacent SPs, while other configurations concerned non-adjacent SPs, at opposite ends of ungrouped lists.

Method

The experimental task in the cue- and the control condition were the same as in the two previous experiments with three exceptions. First, of course, a different set of cues was employed, including "non-adjacent" cues. Second, the cue- and control trials were randomized within trialblocks. Third, the instruction about the intonation of the letters during list presentation was neutral, in the sense that there was no explicit manipulation of intonation mode, because the experiment did not intend to study the effect of grouping. *S*s were merely required to vocalize the consonants at presentation at the same rate as they appeared.

Table 2
Frequency of occurrence of cue- and control signals in experiment 3.

Cue-configuration	Serial position of probe					
	1	2	3	4	5	6
12	3	3	–	–	–	–
15	3	–	–	–	3	–
16	3	–	–	–	–	3
56	–	–	–	–	3	3
26	–	3	–	–	–	3
34	–	–	5	5	–	–
Control signal	2	4	5	5	4	2
Total probe frequency	11	10	10	10	10	11

Note: Each cell entry refers to the number of trials within each block on which the cue signal (row) is presented in conjunction with a certain serial position of the probe (column).

In the cue-condition, six different cue-configurations were employed. Apart from the cues concerning adjacent SPs, i.e., cues "12", "34" and "56", there were three cue-configurations pointing to *non-adjacent* positions, i.e., cue "16", cue "15" and cue "26". Table 2 presents a survey of the cue-configurations, as well as their frequency of occurrence in conjunction with a particular probe-position within each trialblock.

Five male and five female *S*s, between 19 and 26 years of age, participated in all experimental conditions. They were paid for their services and had no previous experience with experiments in short-term retention.

The experiment was run in three 30-min sessions, separated by 30-min pauses. There was a preliminary session devoted to practice on a memory-span task, followed by practice on the experimental task. A session consisted of two trialblocks, each containing 62 trials. The relative frequencies of cue-probe combinations was almost equalized, as shown in table 2. *S*s were informed of these frequencies. The same sequences of letter-lists were used as in the previous experiments. To prevent differential effects of pronunciation times, the specific letters that were probed at each SP and for each cue-configuration were counterbalanced over blocks of trials.

Results

Fig. 5 presents SP-curves for mean RTs of correctly recalled consonants and the precentage of recall errors, for the control and the adjacent cue-condition. It also presents the single data points for the non-adjacent cues. A 2×6 ANOVA was performed on individual mean RTs in the control condition and the adjacent cue-condition, with variables SP and Precueing (control condition vs. condition 12–34–56). Significant effects were found for SP ($F(5,45) = 14.6$, $p < 0.001$), Precueing ($F(1,9) = 138,1$, $p < 0.001$) and for the interaction SP $\times$ Precueing ($F(5,45) = 3.2$, $p = 0.01$). *Post-hoc* Newman-Keuls comparisons at each SP indicated that at all SPs except SP 3,

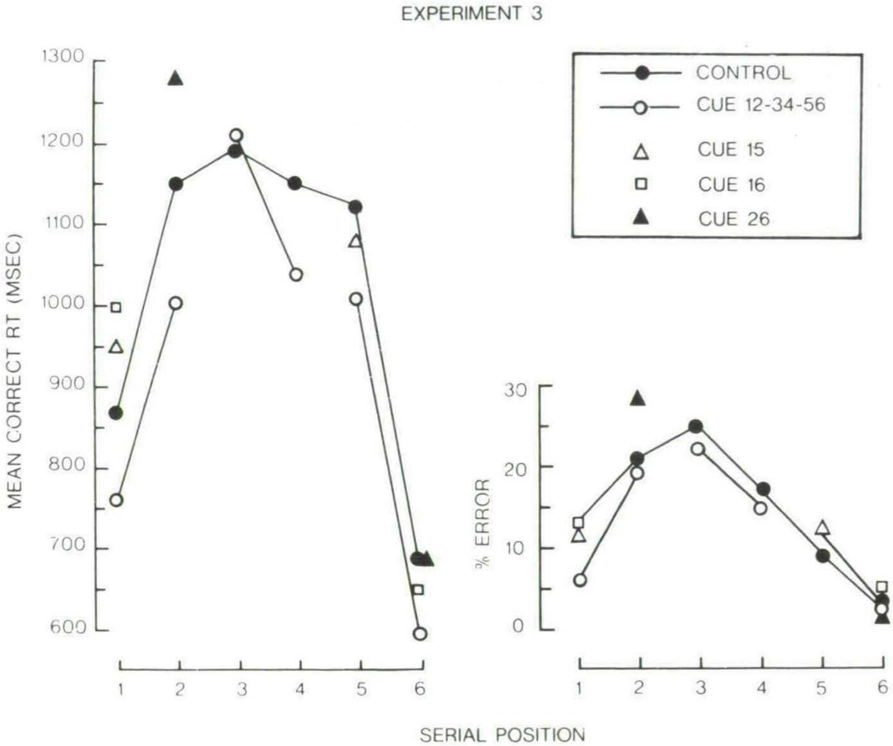

Fig. 5. Mean correct reaction times (left panel) and mean percentages of recall errors (right panel), as a function of serial position, in experiment 3. In the cue-condition, the cue-configurations involving two non-adjacent serial positions, are depicted as pairs of single data points.

mean RTs in the adjacent cue-condition were significantly shorter than in the control condition ($p < 0.05$).

The precueing effects of non-adjacent cues were analyzed by two ANOVA's on individual mean RTs, respectively for SP 1 and 6 and, for SP 2 and 5. Firstly, a 2×4 ANOVA was run on SP 1 and SP 6 with variables SP and Precueing. The four levels of Precueing were: (a) the control condition, (b) the adjacent cue-condition 12–34–56, (c) the non-adjacent cue-configurations "15", "26", and (d) the non-adjacent cue "16". Significant main effects were found for SP ($F(1, 9) = 33.4$, $p < 0.001$) and Precueing ($F(3,27) = 7.5$, $p < 0.001$). *Post-hoc* Newman-Keuls comparisons among the means at SP 1 indicated that all differences were significant ($p < 0.05$). Similar comparisons among the means at SP 6 indicated only a significant lower mean RT for cue "16", as compared with each of the other values.

Secondly, the 2×3 ANOVA on individual mean RTs at SP 2 and 5 included three levels of the Precueing variable; (a) the control condition, (b) the adjacent cue "12" (for

SP 2) and cue "56" (for SP 5), (c) the non-adjacent cue "26" (for SP 2) and cue "15" (for SP 5). The second variable was SP. Significant effects were found for Precueing ($F(2,18) = 14.6$, $p < 0.001$) and for the interaction Precueing × SP ($F(2,18) = 7$, $p < 0.01$). *Post-hoc* Newman-Keuls comparisons among the means of SP 2 indicated that all conditions differed significantly ($p < 0.05$). Similar comparisons among the means at SP 5 indicated no significant differences.

Discussion on experiments 2 and 3

Experiments 2 and 3 confirm the prediction that precueing only improves speed of probed recall when *all* of the precued positions are retrievable *via* a single positional cue. Whenever that condition was not satisfied, the effect of precueing was either absent (experiment 2) or it was beneficial at only one of the precued positions, while it was detrimental to the other position (experiment 3). This supports the view that precueing can only preactivate a single positional cue at a time and that such preactivation is disadvantageous when the probed item cannot be retrieved *via* the activated positional cue.

The results of experiment 2 support the post-hoc explanation of the interactive effects of precueing and grouping in the first experiment, stating that the interaction is caused by a conflict as to which point of access in a grouped list is to be preactivated. It is demonstrated here in a single experiment that in grouped lists, precueing can indeed be either beneficial or neutral, for SP 3 and SP 4 (see fig. 3). Recall at these positions is facilitated by all cue-configurations except by cue "34". In the latter case, the dilemma as to the direction of preactivation hampers direct access. In contrast, in ungrouped lists (monotone condition), the beneficial effect of cue "34" is comparable to the effects of the other cue-configurations.

The monotone condition of experiment 2, replicates the shape of the SP-curve of experiment 1, as well as the constancy and size of the precueing effect. For ungrouped lists, all types of cue-configurations have similar effects. This supports the notion that direct access to either the primacy or the recency cue is preactivated. One anomalous result at SP 3, where hardly any effect of cue "34" is observed, may reflect an incidental grouping effect, that counteracts the effect of precueing. This conjecture is supported by a relatively high error rate at SP 3 in the monotone condition "12–34–56" as compared to cue-conditions "23–45" and "123–456".

The results of experiment 3 also confirm the predictions. The SP-curve in the control condition and in the adjacent cue-condition replicate the basic findings of experiment 1 and 2, although the middle-of-the-list positions are apparently affected by the lack of explicit control over spontaneous grouping strategies. The shape of the control curve is the intermediate between the monotone and inflected curves of experiment 1 and 2. This explanation is consistent with a rather small precueing effect of cue "34".

Fig. 5 confirms the prediction that the non-adjacent cues have antagonistic effects: Precueing is beneficial for the late SP, but at the same time it is disadvantageous for the early item. It appears that when juxtaposed positions are precued, the dilemma as to the direction of preactivation is resolved in favor of the positional recency cue. This is in line with the traditional suggestion of a bias towards recall of recent items (e.g., Bunt

1976), especially in the case of prolonged series of trials. As yet, it is unclear whether this bias is due to accumulating proactive interference among primacy cues of successive lists (Sanders and Willemsen 1978) or whether it reflects a more independent shift in response set.

The adverse effects at early SPs of non-adjacent cues could alternatively be explained by an attentional bias towards one side of the display, invoked by the spatial separation of cue-signals. However, one would expect that besides this "cost", the "benefit" for late SPs to be at least equal to, if not greater than, the effect obtained with an adjacent cue. For example, the observed cost of precueing SP 1 with cue "16" can thus be explained. Yet, the beneficial effect at SP 6 is far less than the effect observed with cue "56". Hence, this alternative explanation seems untenable.

The positive relation between speed and accuracy of recall appears rather uniform in all three experiments, suggesting that the SP-curves are not distorted by speed-accuracy trade-off. Furthermore, experiments 2 and 3 replicate that precueing effects are absent in the accuracy data. This again suggests that accuracy basically depends on the availability of positional cues, but hardly on the moment of direct access (i.e., on whether or not access is *pre*activated). Yet, there is one exception in experiment 3, where non-adjacent cues cause relatively high error rates, in particular at SP 2 (see fig. 5). It is in line with the present view to assume that, when the point of direct access is inappropriate, the necessity to undo that ill-directed preactivation causes both longer latencies and more errors.

General discussion

Two main conclusions can be drawn. First, the effect of serial position of the TBR item is not obscured by effects of identifying the spatial probe position. Hence, the positional probe technique appears to be suitable to study temporal aspects of memory retrieval.

Second, recall latency reveals some interesting properties of the retrieval process, namely, (a) access to a memorized list is obtained only at a single point at a time, and (b) the possible points of access depend on the structure of the memory representation of the list. Joint consideration of the three experiments reveals that precueing generally has a beneficial effect because the list is accessed prior to the presentation of the probe. However, that effect may vanish or turn into a detrimental effect, when the memory structure of the list is not compatible with the precued positions.

The view that retrieval is initiated by access to the list at a *single* point, is an extension of positional cueing theory, in the sense that it explicitly rejects the possibility of multiple parallel access. This theory can also accommodate the idea of a structured list representation in terms of additional retrieval cues at group boundaries. Direct evidence in favor of this view stems from the interaction of the effects of precueing and intonation mode.

Yet, these properties of memory retrieval are also in line with an alternative class of theories on short-term retention, such as Estes' Perturbation theory (e.g., Estes 1972), which assume a hierarchical structure of memory that is non-associative, in the sense that all items in a list are connected to superordinate control elements. Hence, relations among items are based upon commonly shared control elements, rather than inter-item associations. In the most simple case, this implies that an ungrouped list is coded as a single control element to which all individual item-representations are attached. When a list is grouped, the hierarchical structure is extended, in the sense that the sublists are represented by separate control elements at an intermediate level, each of which is attached to the control element for the entire list. At a lower level, individual items within a group are attached to the intermediate control element representing the group. When a list is recalled, the "tree"-structure is decoded from top to bottom. Hence, retrieval from a grouped list always involves an extra decoding step as compared to an ungrouped list. It is not uncommon to assume in this type of theory that the number of control elements involved in the decoding process is positively related to recall latency (e.g., Collins and Quillian 1969). It is also conceivable that precueing preactivates the decoding of control elements at higher levels of the memory structure. This would explain the general beneficial effect of precueing in the monotone conditions of experiment 1 and 2. This view also accomodates the finding that in the inflected conditions, there is no effect of cue configuration "34", since the benefit of decoding the control element for the entire list will be offset by the decoding of the intermediate-level control element of the inappropriate group, on half of the occasions.

However, hierarchical theory runs into major problems with two other findings. First, in grouped lists precueing causes advance decoding and thus, one expects a beneficial effect at both SP 5 and SP 6, when these positions are jointly precued. In figs. 1 and 2, however, the effect only shows up at SP 6. Secondly, Estes' theory cannot explain the detrimental effect of precueing opposite ends of the list in experiment 3. When all items are attached to a single control element representing the entire list, it is expected that precueing is beneficial, irrespective of the precued positions. The theory certainly does not predict *opposite* effects at juxtaposed positions. In short, the present results on precueing fail to support the view of decoding a hierarchical memory structure. This is in agreement with the conclusion of a previous paper (Hendrikx 1984) which discussed more fully the effects of grouping as observed in experiment 1 and 2.

Therefore, the effects of grouping and of precueing are better described by positional cueing theory, if extended with the notion that access to the list can only be obtained at a single point, chosen in accordance with the available retrieval structure.

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CHAPTER 4

THE TIME COURSE OF PRECUEING EFFECTS IN PROBED IMMEDIATE RECALL

Chapter 4 is accepted for publication in Acta Psychologica.

Chapter 4

Abstract

In immediate probed recall of a single item from a six-letter list, some of the serial positions (SPs) were precued at various intervals in advance of recall. Rival predictions on effects of precueing were tested, derived from Sanders' (1975) Positional Cueing Theory (PCT) and from Raaijmakers & Shiffrin's (1980) SAM theory ("Search of Associative Memory"). Vocal recall was prompted by a probe signal, which indicated the position of the requested item. The probe started the reaction time (RT) interval and was presented at various intervals after a precue signal (300-900 msec). The precue indicated a subset of serial positions in which the probe would occur. In SAM theory, prerecent items are retrieved by a cue dependent probabilistic search, while in PCT these items are retrieved by a deterministic inter-item serial search. Since a previous study had shown that precueing preactivates memory retrieval, predictions on how this preactivation would affect recall were derived from PCT and SAM theory. According to PCT, precueing does not change but merely preactivates the retrieval pathway, while in SAM theory, precueing provides additional and more specific retrieval cues. Consequently, PCT predicts only an advantage for latency, while SAM predicts a precueing advantage for both latency and accuracy. Accuracy results clearly supported positional cueing theory instead of SAM theory. Although both theories were in line with the findings on latency, positional cueing theory predicted the particular time course of the precueing effects observed across increasing precue-probe intervals.

Chapter 4 Time Course of Precueing

Latency and accuracy of positionally probed immediate recall have usually been accounted for by hybrid models of memory retrieval, according to which early and middle-of-the-list items are retrieved by means of a serial search, while only the more recent items are accessed and retrieved in parallel. Two distinct theories of this type are Sanders' (1975) "positional cueing theory" (PCT) and Raaijmakers & Shiffrin's (1980; 1981) SAM theory ("Search of Associate Memory"). These theories mainly differ on the question whether serial search is a deterministic forward search from item to item (as in PCT) or rather (as in SAM), a probabilistic search of an associative memory network.

According to Raaijmakers & Shiffrin's SAM theory, retrieval of prerecent items consists of a cue dependent probabilistic search of an associative memory network, followed by a recovery process. Search is guided by contextual cues and every recalled item serves as an additional retrieval cue. Search consists of a number of discrete steps, each involving a sample of an image from long-term store. The sampling probability of a memory image depends on the associational strength of the available retrieval cues with that image, relative to the strengths of these cues with all other images. In SAM theory, retrieval processes are of limited capacity, firstly because there is a limit on the number of retrieval cues that can be used to sample at one time. Secondly, while retrieval cues can simultaneously activate a number of memory images, only a single image can be retained long enough to be recovered. Recovery consists of evaluation of a sampled image and response decision. SAM theory further assumes that recall failures are due to retrieval failures, resulting from weaker associations of the available retrieval cues at the time of test with the desired memory image and with the context in which it was acquired. Apart from serial retrieval of <u>pre</u>recent items from long-term store, SAM theory assumes that the recent items are retrieved via parallel access from a short-term buffer.

Whereas SAM theory has been succesfully applied to the results of studies on free recall, paired associate recall and recognition (Raaijmakers, 1979; Raaijmakers & Shiffrin, 1980), the present study attempts to apply SAM theory to positionally probed recall and to compare predictions that can be derived from SAM with those of positional cueing theory (PCT).

Positional cueing theory proposes that storage is unitary and that all items are retrieved after the list has been accessed at a particular serial position by means of a "positional cue", which of the list. The number of positional cues is limited and only one positional (i.e., retrieval) cue can be used at a time to obtain access to the list. The point of access that has been chosen determines whether and how a particular item will be retrieved. An item in the first part of the list is retrieved by way of a forward inter-item serial search which is self-terminating. The search starts after direct access to the memory representation of the first item is accomplished via a positional primacy cue. Direct access and serial search are separate and successive stages of retrieval. According to PCT, the last few items can each be directly and simultaneously accessed, due to their association to a positional recency cue. As this association becomes progressively stronger for more recent items, there is a decrease of recall latency and of errors across the last few SPs.

Both PCT and SAM theory can account well for the results obtained with the positional probe paradigm, which show bow-shaped serial position (SP) curves for recall accuracy and latency, with an advantage for primacy and a recency items and a steady increase of RT across the first few SPs (e.g., Moss & Sharac, 1970; Sanders & Willemsen, 1978; Hendrikx, 1984 a). Yet, there is strong support for only PCT in a study on the effects of precueing in positionally probed recall (Hendrikx, 1984 b): After presenting a serial list of items, a single to-be-recalled item was prompted briefly by a positional probe (i.e., one light at a particular position in a linear array), indicating the serial position of the requested item. (See figure 1). When the number of possible probe locations was reduced by precueing a subset of locations briefly in advance of the probe, it was found in most cases that recall latency was substantially reduced, but accuracy was not affected. These findings were taken to suggest that precueing preactivates memory retrieval during the interval preceding the recall probe. More importantly, however, it was found that the precueing advantage vanished or even turned into a detrimental effect when two locations at either side of the list were precued, or when the list was subjectively grouped into two sublists and the cued locations were at either side of the boundary between the sublists. It was therefore concluded that (a) preactivated memory access can occur only at a single

Figure 1

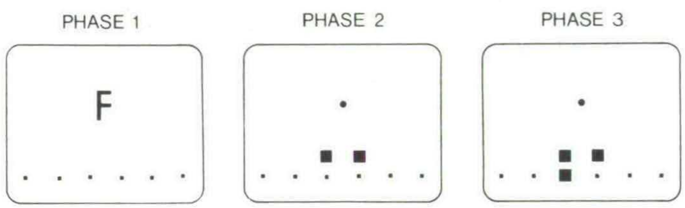

Figure 1: From left to right: three phases of a trial. Continuous display of horizontal row of 6 luminous dots, during all phases. Leftpanel: Presentation of items at the centre of the screen. Middlepanel: Presentation of a precue signal above a section of the dot row. Rightpanel: Presentation of positional probe at one location in the dot row, indicating the requested serial position.

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point, such as the beginning or end of the (sub)list, and (b) when the to-be-recalled memory item cannot be retrieved via the retrieval pathway that has been preactivated by the precue, the search must be aborted and this tends to increase recall latency and errors. In contrast to PCT, it remains unclear how SAM theory could account for the adverse effects of precueing. SAM theory would rather expect that when an additional retrieval cue is inadequate, it would simply have no effect at all. Therefore, the present study aims to provide a more thorough test of contrasting predictions of PCT and SAM theory with regard to precueing in positionally probed recall.

The present study attempts to test the PCT and SAM retrieval model by measuring the effects of precueing the serial position of the to-be-recalled item. Latency and accuracy of probed recall were the main variables: As in the previous studies (Hendrikx, 1984 a,b), the probe indicated the position of the requested item, since it occurred at one particular position in a horizontal row of luminous dots, presented on a CRT. (See figure 1). The serial positions of the successive items comprising a list were visualized by this display. The first position in the row indicating SP 1, the second position SP 2, etc. (from left to right). Presentation of the probe started the reaction time (RT) interval, to be terminated by the subject's response. Precueing reduced the number of possible probe locations, by presenting a precue signal briefly in advance of the recall probe. (The precue signal always pointed to a subset of the lights from the linear array, and the probe always occurred in that subset.)

Since there is strong evidence that precueing at a 300 msec interval preactivates retrieval processes (Hendrikx, 1984 b), it was reasoned that a gradual increase of the precue-probe interval should reveal the progress of preactivated memory retrieval and some of its properties. Therefore, the precue-probe intervals were varied between 300 and 900 msec. In the following, these interval durations will be termed "stimulus onset asynchronies" (SOAs) between the presentation of precue signal and probe. Of course, increasing SOA implies a longer retention interval. Therefore, a greater precueing advantage as a function of SOA can only be observed relative to control conditions with the same variation of the retention interval, in which an uninformative control signal substitutes the precue signal. Thus, precueing effects can be assessed independent of any recall decrements due to longer retention intervals. As in the previous precueing study, the present experiment employed six-item lists, and two adjacent items were simultaneously precued (i.e., SP 1 and 2, SP 3 and 4, or SP 5 and 6), in the cue condition.

With respect to recall <u>latency</u>, positional cueing theory (PCT) predicts that precueing reduces RT and that the reduction is a positive function of the precue-probe interval: PCT assumes that precueing with a SOA of 300 msec preactivates at least the first retrieval stage, i.e., direct access to either the first or the last few items (Hendrikx, 1984 b). Therefore, recall of all prerecent items, requiring direct access to the first item, will equally benefit from preactivation of direct access caused by precueing. In addition to this "access effect", longer SOA durations should also cause preactivation of the next retrieval stage, that is, of serial search, as soon as access to the first item is accomplished. This "search effect" will cause an additional benefit for the second item as SOA grows longer, and, possibly, subsequent items

Table 1

Effects of Precueing on Recall as predicted by SAM theory and positional cueing theory (PCT)

	S A M	P C T
SP 1 , 2	- advantage at both SPs. - with longer SOAs gradual smoothing out of precueing differences between SPs. - improved recall accuracy.	- at short SOA, equal advantages; with longer SOAs increasing effect at SP 2. - no effect on accuracy.
SP 3 , 4	- same as for SP 1 , 2	- at short SOA, advantage at only <u>one</u> SP; with longer SOAs effect at both SPs. - no effect on accuracy.
SP 5 , 6	- at short SOA, no effect. - with longer SOAs larger advantage at SP 5. - with longer SOAs, possibly better accuracy at SP 5.	- largest advantage at SP 5. - effect at SP 5 larger than at SP 6, increasing with longer SOAs. - no effect on accuracy.

Note: Precueing effects are relative to the control condition. Effects are on latency, unless otherwise indicated.

will benefit as well. However, a "search effect" should progress across SPs in the same order and direction as proceeds serial search. Hence, the second SP will be the first to show a benefit. Improvements of the third and later items may also occur as a result of the two-stage effect, although this may require even longer SOAs. However, this prediction wil not be tested, since it would imply incorrect precueing (e.g., probing SP 3 after precueing SPs 1 and 2). Note that PCT explicitly predicts no "search effect" at the first serial position, since for this position preactivation of serial search is irrelevant. Predictions are summarized in table 1.

Precueing the two middle-of-the-list positions (SP 3 and SP 4) may present a dilemma as to which retrieval pathway is preactivated. In a number of cases, the item at SP 4 will be retrieved by means of access via the positional recency cue, rather than by the time consuming forward serial search. When precueing preactivates direct access via the recency cue instead of via the primacy cue, this will be detrimental to the recall of SP 3, since SP 3 has a far weaker bond with the recency cue. Alternatively, when precueing prompts direct access via the primacy cue, SP 3 will benefit from serial search, relative to SP 4. Therefore, PCT expects that, depending on a subject's bias, a precueing benefit will occur either at SP 3 or at SP 4, but not at both SPs. Yet, with sufficiently long SOAs this rivalry will be solved, as both retrieval pathways may become preactivated in succession.

In case of precueing the last two items, positional cueing theory predicts a greater benefit of precueing for SP 5 than for SP 6, since the penultimate item has a weaker bond with the retrieval cue. Precueing will diminish this disadvantage, since the weakest association has the most to gain from preactivated access via the positional recency cue, and this is even more so with longer SOA durations.

With respect to recall accuracy, positional cueing theory predicts no effects of precueing, for any duration of the precue-probe interval. As already argued (Hendrikx, 1984 b), accuracy appears to depend on the availability of (positional) retrieval cues, but hardly on whether that retrieval cue is used before or after probe presentation. Precueing does not change the retrieval pathway, which is thought to determine accuracy at a given position.

Although SAM theory has not yet been explicitly applied to positionally probed recall, some predictions on the effects of precueing at various intervals in advance of the recall probe can be deduced.

(See table 1.) SAM theory predicts that precueing reduces both recall <u>latency</u> <u>and</u> <u>accuracy</u> of all prerecent items. As these items are retrieved from the long-term store by means of a probabilistic search, the precue signal will enable the subject to sample the desired item with more specific retrieval cues concerning its positional attributes. In the present experimental task, the serial positions of successive items were indicated by means of a spatial display, that is, a row of dots (see figure 1), presented during the entire trial. It served as a frame of reference for both the position of the probe signal and the precue signal. Subjects were instructed to associate each spatial position in the display with the temporal position of a particular list item. It was reasoned that a precue signal -- pointing at a subset of positions -- would evoke some of the positional attributes of the memory representations of some items. In SAM theory, these attributes operate as retrieval cues for these items. The precueing advantage should increase with longer precue-probe intervals, since memory search is probabilistic and therefore increasingly accurate when more time is available to sample the desired image with more particular retrieval cues. In short, SAM theory predicts a precueing effect on accuracy while PCT does not.

In SAM theory, prerecent SPs may possibly be affected by precueing in different degrees. For example, a precue signal at SP 1 and SP 2 may elicit a retrieval cue with possibly stronger associations to the first item than to the second item, so that the precue signal would produce a greater advantage at SP 1. However, regardless of the actual differences in precueing effectiveness between items, these differences should be most clearly observed at short SOA durations. With longer SOAs, the item of a pair with the larger initial benefit will be retrieved during the precue-probe interval and then serve as an additional retrieval cue for the remaining item. As a result, longer SOAs will cause a gradual smoothing out of the differences in precueing effects within a pair of precued items.

For the two most recent items, SAM theory predicts no precueing advantage, since these items are recalled from the short-term buffer without the use of retrieval cues. With a short SOA, the recency part of the SP-curve merely reflects encoding, in the sense that these items are still in an activated state (in various degrees). However, with sufficiently long SOAs, both items may be rehearsed and this may gradually eliminate the relative recall inferiority of SP 5 over SP 6 as the SOA grows longer. This would not be expected to occur at a SOA as short as 300 msec, as the rate of implicit speech has been estimated at 200 msec/item (Landauer, 1962). Thus, for longer SOAs, the precueing advantage at SP 5 may also involve accuracy. (See table 1.)

A possible methodological problem with precueing should be briefly mentioned here. As already argued previously (Hendrikx, 1984 b), perceptual factors may also contribute to the precueing effect in probed recall. Precueing may well facilitate perceptual discrimination of the probe location, thus reducing RT. Hence, care should be taken not to interpret perceptual effects as reflecting memory processes. However, it was shown in previous studies (Hendrikx, 1984 b; 1985), that with the present type of display and paradigm, perceptual effects appear to be of minor importance, since they are relatively small and do not affect the shape of the SP curve for recall latency (see footnote).

Method

Tasks and Subjects

In each trial, six visual consonant letters, randomly chosen without replacement from the set F, J, K, L, M, P, R, T, Z, were presented in succession, all at the same place just above the center of a CRT, at a rate of 2 items/sec. At a variable interval after presentation of the list, a probe signal appeared, consisting of the onset of a single light that was located in one of six possible

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Footnote: Precueing effects were substantially greater with the probed recall task (Hendrikx, 1984 b) than with a 6-choice pointing task (Hendrikx, 1985). Assuming that a perceptual factor is of equal importance in both tasks, the perceptual component of the precueing effect is _a fortiori_ limited to a fraction of the relative small precueing effect observed in the pointing task. Secondly, this fraction is apparently small, since the precueing effect in the pointing task was shown to depend mainly on non-perceptual task variables. Thirdly, for probed recall latency, the shape of the SP curve was not affected by precueing, which indicates that the discriminability of probe locations is not _differentially_ affected by precueing (Hendrikx, 1984 b).

positions in a horizontal array. (See figure 1). The probe indicated the SP of the requested item, i.e., SP 1, 2, 3, etc. from left to right in the array. The subjects vocally recalled the probed item upon presentation of the probe as quickly and accurately as possible. RT was the interval between probe onset and response initiation.

Within trialblocks, trials were randomly assigned to either precue or control condition. In the precue condition, the last letter of the list was followed, after a 500 msec interval, by one of three possible precue signals. The precue provided partial advance information about the location of the forthcoming probe signal. It consisted of two lights from a horizontal array of six lights, positioned slightly above the aforementioned probe array. The pair of precue lights was in one of three possible locations, i.e., occupying positions 1 and 2, or 3 and 4, or 5 and 6 (from left to right). The precues (here labelled "12", "34", and "56") were equiprobable. The probe always occurred randomly and equally often at one of the two precued positions. Subjects were instructed to attempt to use this advance information to speed up their recall. In the control condition trials differed only from those in the precue condition in that a control signal was presented instead of a precue signal. The control signal had the same temporal properties as the precue, but consisted of all six precue lights, indicating that all probe positions were equiprobable.

In both the precue and control condition, the probe was presented after a variable interval following onset of the precue or control signal. The stimulus-onset asynchrony (SOA) between the precue (c.q. the control signal) and the probe was 300, 500, 700 or 900 msec. The probe lasted 2.5 sec and was displayed at twice the intensity of the other lights. After the simultaneous offset of all signals, a blank interval of 3 sec preceded the next trial.

In order to prevent effects of grouping, (e.g., Hendrikx, 1984 a,b) subjects were instructed to vocalize the items during presentation in a monotonous way, i.e., without stressing a letter or changing voice inflection. This was well practiced in advance and continually monitored. Subjects practiced to adopt a rate of speech similar to the rate of letter-presentation.

Four male and 4 female students of Tilburg University, between 19 and 26 years of age, participated in the experiment. They were paid and had no previous experience in memory tasks.

Apparatus and Display

A subject was seated in a dimly lit, sound attenuating room and faced a computer-controlled scope (Digital GT-40), at a distance of about 130 cm. Trial onset was signalled by a 500 msec tone of 2900 Hz (65 dB). One sec after the tone, 6 capital letters (height 22 mm, width 11 mm) were sequentially presented (2/sec) in the area surrounding the fixation point. Each letter remained visible for about 300 msec. During all trials, seven luminous dots (1 mm in diameter) were on continuous display. One dot served as a fixation point and was located 17 mm above the centre of the scope. The other six dots made up the probe array, consisting of a horizontal row, at equidistant intervals (11 mm), at 35 mm symmetrically below the fixation point. The probe signal consisted of a luminous square (2 x 4 mm), superimposed on one of the dots. The precue lights had a similar shape and were located 8 mm above the probe array.

Procedure and design

All subjects participated in six experimental sessions, preceded by a practice session. Each session consisted of two trial blocks, separated by a 2-min break. SOA was varied between trial blocks. Each of the four SOA durations occurred once in two successive sessions. Order of SOA durations was counterbalanced across trial blocks and subjects.

A trial block consisted of 60 trials, preceded by 4 warm-up trials. Within a block, (a) each SP was probed 10 times, (b) no SP was probed more than twice in succession, (c) none of the letters was requested for recall more than twice in succession. In addition, apart from some minor deviations, each letter from the set was probed once at each SP. Precue condition (i.e., precue vs. control) was varied within each block of trials. Over two successive trial blocks, each SP was probed 10 times in each precue condition.

In all SOA conditions, the same sequences of letter lists were employed. Two different sequences of 60 six-letter lists were composed. Within a list, there neither were repetitions of letters, nor did any letter occupy the same SP in any two successive lists. In order to reduce possible sequential effects, a mirrored variant of each of the two sequences was also employed in which the order of the lists as well as the within-list order of letters in each list was inverted. In each inverted list, the SP of the probe was mirrored relative to the middle of the list. Thus, the probe pointed towards the same consonant as in the original list. In two successive sessions, the four list sequences were used once. The four list sequences were assigned to trial blocks so that each sequence occurred once in each of the four SOA conditions. For each SOA and precueing condition this yielded a total of 15 RT measurements at each SP per subject, about equally divided over the nine letter-alternatives. This minimized possible RT artifacts resulting from differences in the pronunciation of the consonants.

In the practice session, subjects practiced a 6-item memory-span task with ordered written recall and two blocks of 60 practice trials on the experimental task. In the practice session, subjects received knowledge of results on speed and accuracy. The experimental sessions

Figure 2

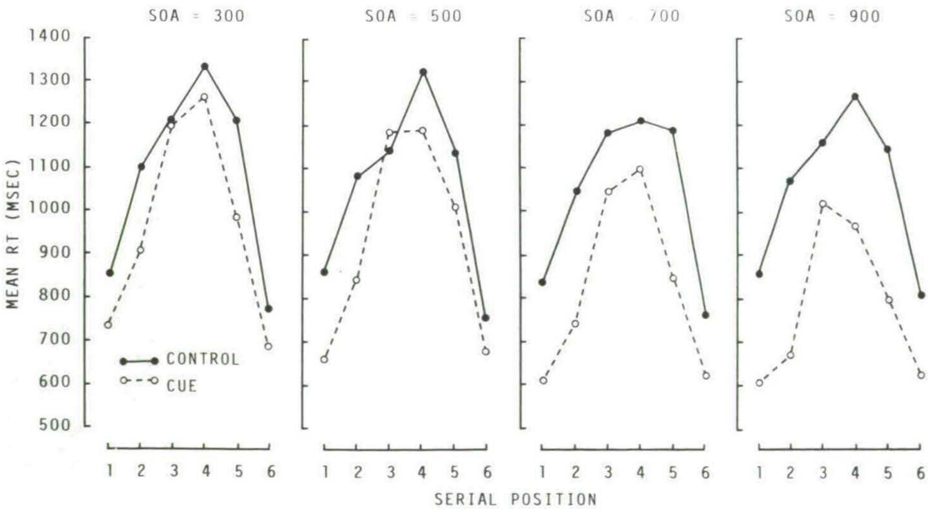

Figure 2: Mean reaction time (RT) as a function of serial position in the control condition (solid lines) and the precue condition (dashed lines) for various durations (msec) of the precue-probe interval (SOA). Data are averaged over 8 subjects.

lasted 30 min and were separated by 30-min breaks. The experiment was run on two successive days. On the first day, the practice session and two experimental sessions were run. The four remaining sessions were run on the second day.

Results

Figure 2 presents mean RTs for correctly recalled items as a function of SP, for each SOA duration. In all conditions, percentages of recall errors have bow-shaped SP curves, similar to those for RT. Error latencies are substantially longer than correct latencies (typically over 100 msec). Table 2 presents proportions of errors, averaged over subjects, for each pair of SPs in each condition. In the two first SP pairs, there is a slight advantage in the precueing condition, in 5 out of 8 comparisons. However, there is no trend for improved accuracy with increasing SOAs in either condition.

Differences between the cue and control condition in the number of errors were tested, within each pair of SPs with Wilcoxon's matched-pairs signed-ranks tests (Siegel, 1956). Critical and observed *T*-values are shown in table 2. None of these tests showed a significant difference between conditions, except at SP 5,6 with SOA=300 ms. Moreover, the majority of observed *T*-values substantially exceded the critical *T*-values at the 0.025 rejection level (one-tailed). Thus, the one-tailed hypothesis concerning a *decreased* error rate caused by precueing should be rejected. However, a further test of this hypothesis seems appropriate, since in the above tests, the actual number of pairwise comparisons between conditions was small, ranging between 8 and 13, due to ties. (The maximal number of comparisions was 16: 8 subjects x 2 SPs). Therefore, an additional analysis was run on the accuracy data, pooled across the first four SPs, to test the prediction of SAM theory that precueing improves accuracy for prerecent items. Arcsine transformed individual proportions of errors were calculated, pooled over SP 1-4. Proportions were based on 60 trials for each subject. An ANOVA on the individual transformed error scores was performed, with factors Precueing (precue vs. control) and SOA. There was no significant effect of Precueing ($F(1,7)=3.02$, $p=0.12$), nor of SOA ($F(3,21)=0.45$, $p=0.72$), nor of the SOA x Precueing interaction

Table 2

Error rates and Wilcoxon's *T*-tests on error frequencies.

SOA		SP 1 + 2		SP 3 + 4		SP 5 + 6	
300		control	cue	control	cue	control	cue
	prop. errors:	.12	.08	.24	.18	.05	.04
critical *T*		8		8		8	
observed *T*		9.5		34		8	
500		control	cue	control	cue	control	cue
	prop. errors:	.10	.08	.25	.25	.04	.03
critical *T*		14		17		6	
observed *T*		28		48		20	
700		control	cue	control	cue	control	cue
	prop. errors:	.10	.10	.26	.22	.05	.04
critical *T*		4		11		4	
observed *T*		18		20.5		13	
900		control	cue	control	cue	control	cue
	prop. errors:	.12	.08	.22	.22	.07	.05
critical *T*		14		17		4	
observed *T*		22		39.5		10.5	

Note on table 2: see next page

($F(3,21)=0.99$, $p=0.58$). In a similar ANOVA on accuracy at SP 5 and 6 (pooled), no significant effect were found ($F<1.1$ in all tests).

A 4x2x6 ANOVA was performed on individual mean RTs, with SOA, Precueing (precue vs. control), and SP (1-6) as variables. All main effects were significant; SOA: $F(3,21)=9.9$; Precueing: $F(1,7)=98.3$; SP: $F(5,35)=14.5$; $p<0.001$ in all cases. In addition, two interactions were significant, i.e.: Precueing x SOA: $F(3,21)=10.1$, and Precueing x SP: $F(5,35)=5.9$, $p<0.001$ in both cases. These interactions indicate that the precueing effect is a positive function of SOA and also a function of SP. The Precueing x SOA x SP interaction did not reach significance ($F<1$). Analysis of the simple main effects (Betz & Levin, 1982) of the Precueing x SOA interaction showed that SOA did not affect the control condition but significantly reduced RT in the cue condition. In addition, at all SOA durations mean RT of the cue condition was faster than the control condition (*df*=47, *MS-error*=112.5, i.e., *MS* of Precueing x SOA x Subjects).

For each SP, a separate 4x2 ANOVA on individual mean RTs was performed, with variables SOA and Precueing. Significant interactions between effects of Precueing and SOA were found at all SPs except SP 3 and SP 4 ($p<0.05$, see table 3 for details). Simple main effects of the significant interactions of the SPs 1, 5 and 6, showed significant precueing effects for all SOAs, while for SP 2 Precueing was significant for all SOAs except for the 300-msec SOA.

Figure 2 suggests that particularly with longer SOAs, precueing effects differ substantially within each pair of SPs precued by a common signal. It appears that the precueing advantage at SP 2 gradually becomes superior to SP 1, and, similarly, the advantage at SP 5 becomes increasingly superior to SP 6. This trend was confirmed for each SOA

Note on table 2:
Critical *T*-value of Wilcoxon's matched-pairs signed-ranks test for which the 0-hypothesis is rejected at the 0.05 level (2-tailed). All observed *T*-values exceed or equal the critical *T*-value and therefore indicate that cue and control condition do not differ significantly in number of errors.

Table 3

ANOVAs of recall latency per serial position (F-values)

		Serial Position					
Source	df	1	2	3	4	5	6
A: Precueing	1,7	7.7*	11.2*	10.9*	8.3*	10.2*	0.5
B: SOA	3,21	23.7***	37.4***	2.5	6.2**	32.4***	16.0***
A x B	3,21	4.9**	3.8*	2.0	0.4	6.2*	7.9**

Notes: *** p<0.001; ** p<0.01; * p<0.05.

duration by a set of three 2x2 ANOVAs on individual mean RTs, one for each pair of adjacent positions, with factors SP and Precueing. The analyses were separately conducted on three pairs of adjacent SPs precued by a common signal (i.e., SP 1 vs. 2, SP 3 vs. 4 and SP 5 vs 6). Statistics are presented in the Appendix. The ANOVAs on SP (1,2) showed significant main effects for both SP and Precueing at all SOAs ($p<0.01$ in all cases). The interaction SP x Precueing reached significance only for SOA=900 msec ($p=0.04$). In the ANOVAs on SP (5,6), both main effects and the SP x Precueing interaction were significant for all levels of SOA duration ($p<0.01$ in all but one cases). In the ANOVAs on SP (3,4), a significant main effect of Precueing was only found for SOAs of 700 and 900 msec ($p=0.01$, resp. 0.02). Neither the main effect of SP, nor the SP x Precueing interaction was significant for any SOA duration for SP 3 and 4. In short, these analyses of SP-pairs suggest a contrast between the first two and last two SPs: For the most recent pair of items the SP x Precueing interaction occurs regardless of SOA duration, whereas for the first two items the interaction occurs only with the longest SOA.

Discussion

SP curves in both the precue and control condition show the typical bowed shape. Even with the shortest SOA duration recall was substantially faster in the precue condition than in the control condition, at least at most SPs. Precueing caused an advantage in recall latency but not in accuracy, while SP affected both variables. This confirms the results of Hendrikx (1984 b) and extends their validity across a wider range of SOA durations.

Accuracy is not consistently affected by precueing, not even with the longer SOAs, despite substantial error rates in all conditions. This was predicted by positional cueing theory: Precueing does not change but merely preactivates a retrieval pathway and, hence, it only affects latency. In contrast, this finding does not confirm SAM theory's prediction that precueing progressively decreases error rates with longer SOAs, particularly at prerecent SPs.

In the control condition, SOA duration neither affected RT nor accuracy in any part of the list. This seems to exclude the possibility that manipulation of SOA duration would cause differential forgetting due to variation of the retention interval.

<u>Precueing SP 1 and SP 2:</u> Figure 2 shows that for brief SOAs, RTs of the first two items are equally affected. Although this finding is in accord with both PCT and SAM theory, it was explicitly predicted by PCT, according to which precueing first preactivates direct access, which is of equal importance to both items.

It is also found that prolonging the precue-probe interval (SOA) enhances the beneficial effect of precueing on recall latency. Both PCT and SAM theory are in line with this observation, as well as with the finding that the precueing advantage at SP 2 tends, with longer SOAs, to become greater than at SP 1.

According to PCT, this steady decrease of slope with longer SOAs suggests a gradual progression of retrieval preactivation which extends beyond direct access to include a pre-search for the second item. Thus, search is also affected when precueing occurs sufficiently in advance of the probe. As a result, both the first and the second item are available in "working memory" at the time of probe presentation.

<u>Precueing SP 3 and SP 4:</u> With brief SOAs, there was no precueing effect at SP 3 and a substantial effect at SP 4. With increasing SOAs, the precueing effect gradually evolved at SP 3. This pattern of results was explicitly predicted by PCT, according to which precueing at short SOAs creates a dilemma as to the choice of the retrieval pathway (i.e., forward search or direct access). For the majority of the subjects, this dilemma is apparently solved in favor of SP 4 and to the detriment of SP 3. With longer SOAs, both pathways will be preactivated in succession, and thus precueing becomes also beneficial to SP 3. In SAM theory, this result can be accounted for <u>post hoc</u> by assuming that the precue signal elicits a retrieval cue that is more effective in activating positional attributes of the fourth item.

<u>Precueing SP 5 and SP 6:</u> At the shortest SOA, the reduction of latency caused by precueing was greater at SP 5 than at SP 6. This was predicted by PCT, but not by SAM theory, as the rate of implicit speech (about 200 msec/item) requires longer SOAs for a precueing effect to occur at all. The superiority of the precueing effect at SP 5 gradually grew stronger with increasing SOAs. This finding is in accord with both PCT and SAM theory. The finding confirms the notion of PCT that the strength of the backward association with the positional recency cue is weaker for less recent items (Hendrikx, 1984 b): Although direct access

makes both items available in advance of the probe, precueing will be more beneficial for the weaker bond to SP 5. The fact that this greater advantage for SP 5, as compared to SP 6, is found at the shortest SOA, presents an interesting contrast with the results on the first item pair, where the precueing effect at SP 2 only tends to become greater than at SP 1 with longer SOA's. This underlines that retrieval processes for recent items are entirely different than those for prerecent items. It also supports PCT, according to which direct access is possible to both of the last two items, while SP 2 can only be accessed via SP 1.

In summary, the time course of precueing in probed recall provides more support for positional cueing than for SAM theory. Although both theories were in line with the findings on latency, positional cueing theory predicted the particular time course of the precueing effects across increasing durations of the precue-probe interval. However, the finding that precueing does not promote accuracy only supports positional cueing theory. An explanation of the present results with SAM theory would require a probabilistic search process, that can be speeded up by additional retrieval cues on positional attributes of the to-be-recalled item, while the output quality of the search process should nevertheless remain unaffected.

Appendix

The statistics of the 12 ANOVAs discussed above are ordered here by SP-pairs. For each pair the *F*-values are presented successively in the order of increasing SOA duration. In all cases $df=1,7$. SP 1 and 2: Precueing: $F=68.6$; 21.3; 74.8; 37.8; $p<0.01$ in all cases. SP: $F=31.6$; 34.0; 26.5; 5.7; $p<0.01$ in all cases. Precueing x SP: (significance only for SOA=900 msec) $F=5.7$, $p=0.04$. SP 3 and 4: Precueing: (significance only at SOA 700 and 900 msec) $F=11.0$, $p=0.01$; $F=8.9$, $p=0.02$. SP 5 and 6: Precueing: $F=30.1$; 22.2; 32.1; 67.8; $p<0.01$ in all cases. SP: $F=28.8$; 41.0; 17.2; 17.1; $p<0.01$ in all cases. Precueing x SP: $F=31.9$; 7.4; 25.3; 14.3; $p<0.01$, except for SOA=500 msec: $p=0.03$.

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CHAPTER 5

ON THE ORIGIN OF PROACTIVE INTERFERENCE IN SHORT-TERM RETENTION

Chapter 5

Abstract

This study tests predictions of the positional cuing theory of short-term memory about proactive interference (PI). Vocal RT was used to measure the speed of retrieval in positionally probed immediate recall. Pairs of closely spaced lists were auditorily presented, the first list serving as a non-PI trial, the second as a PI trial. Pairs were separated by a long interval to allow for dissipation of PI. Lists consisted of consonants or of a prefix digit followed by consonants. The results showed inverted-U shaped serial position (SP) curves for all list types. In the PI trials, RT was prolonged for consonants in the first part of the list. This effect was constant over the affected SPs. Effects of PI increased as a function of the degree of similarity of the first item of the first and second list. The results support the positional cuing theory, which states that PI impairs recall because of inter-list confusion between the positional primacy cue associated to each first item. The results neither support explanations in terms of attentional bias, differential encoding or acid-bath theory.

Chapter 5 Origin of PI

Ever since the classical work by Keppel & Underwood (1962), proactive inhibition (PI) has been shown to be a reliable phenomenon in most short-term retention paradigms (e.g., Crowder, 1976, for a review). Generally, PI consists of a memory decline which is observed in successive trials with similar material. The effect builds up in only a few trials (Wickens, Born & Allen, 1963), while PI rapidly disappears when an interval of at least 2 min intervenes between trials (Loess and Waugh, 1967).

The possible mechanism underlying PI can in principle operate in three phases, that is, at the time of acquisition, during storage or at the time of retrieval. Hence, three main theoretical positions on the origin of PI have been proposed. The encoding explanation of PI essentially states that the repeated presentation of similar materials over successive trials causes insufficient learning or less distinct encoding, due to a decrement of attention. Alternatively, the storage theory of PI asserts that later trials may suffer more from decay during the retention interval, due to the presence of earlier traces. It is the common consequence of the encoding and the storage view that there is less of the to-be-recalled information available at the time of test. In contrast, PI may reflect problems in the retrieval of information that has been adequately encoded and retained. In this view, there is no loss of availability of stored information, but in later trials retrieval is hampered by competing traces from previous trials. Thus, the memory trace pertaining to a later trial is available but not accessible, since the it is not only the strength of the trace that counts but also the strength of the competing traces. With an increasing number of prior trials with similar materials, it becomes increasingly difficult to discriminate the last trial from earlier trials, or to even generate the appropriate trace, instead of competing traces.

The view that PI is due to storage loss (decay) during the retention interval is found in two related theories on short-term forgetting, viz. the "acid bath theory" (Posner & Konick, 1966) and Estes' (1972) "associative coding" theory (or "perturbation theory"). Acid bath theory assumes that traces decay at a rate set by the amount of similar information in store, i.e., by the concentration of the acid. The rate of decay depends on factors such as similarity, list length and interlist interval. One important consequence of this theory is that it predicts cumulative effects of interference within a list; Middle-of-the-list items are weaker and thus they should be more susceptible to PI. Another consequence of acid bath theory is that PI should vary as a function of previous list length.

Estes' associative coding theory also explains forgetting and PI as interference at the storage level; PI promotes trace decay which consists of increased disturbances of the relative temporal positions occupied by successive inputs at each encoding level (e.g., features, items, list segments, lists). Hence, memory for a particular item is derived from memory for order of the constituent features of that item and of the items in its immediate vicinity.

The retrieval theory of PI can well accommodate the phenomenon of "release from PI". Recall performance improves after a shift of semantic category of the to-be-remembered materials, since a shift helps to differentiate between successive lists.

The results of a number of studies have cast some doubt on the encoding explanation of PI. For example, Watkins & Watkins (1975) and Loftus & Patterson (1975) found that, after a shift of type of material in a series of Brown-Peterson trials, the first post-shift trial was released from PI (see also Wickens, 1972). Release from PI can be explained by either an encoding, storage or retrieval hypothesis. However, release from PI is a temporary phenomenon, since it does not occur in a final free-recall test of all trials. This has been taken as evidence against an "availability explanation" of PI, that is, in terms of factors operating on encoding or storage. If the successive trials are differentially encoded, this should also be reflected in final free recall. On the other hand, when successive trials are progressively harder to discriminate, the advantage for the first trial should be temporary and it should not be reflected in final free recall, which does not rely on information on occurrence at a specific trial. However, Radtke & Grove (1977) have objected that the delayed-recall results are no prove against differential encoding or storage, since an availability advantage for early trials may be suppressed by confounded effects of retroactive interference from later trials.

Sanders (1975) has elaborated the retrieval hypothesis by proposing that PI is the consequence of a conflict in accessing the beginning of a list. According to this view, the quality of short-term recall depends mainly upon direct access to items at particular serial positions in the list. Recall of the most recent items would occur through direct access via positional recency cues, while the positional primacy cue provides direct access to the first item. Middle items are recalled by means of a serial search through subsequent item representations, starting at the first item. PI would then be due to confusion of the positional primacy cues of two successive lists, which impairs direct access to the first item and, hence, delays the subsequent serial search. The most recent items are not vulnerable to PI, since the recency cue of the most recent list has not been weakened by a retention interval. Evidence in favor of this "positional-cueing hypothesis" was found in a study by Sanders & Willemsen (1978) in which latency of succesful recall of single items was measured to assess the effects of PI on memory retrieval. That study measured reaction time (RT) to a positional probe, which indicated the serial position of the requested item. The increase of RT caused by PI was independent of previous list length, it was constant across serial positions within the primacy part of the list, and it did not occur at the recent serial positions. Both findings are hard to explain in terms of acid-bath theory, which would expect stronger effects of PI, as traces are weaker and as there is more "acid" contributed by the previous list.

A similar type of result was recently obtained by Wickens, Moody & Dow (1981) in a Sternberg (1969) memory-scanning recognition task. They found a buildup of PI across trials, by way of longer RT, whenever a filled retention interval intervened between presentation of the memory set and the recognition probe. The size of PI was independent of set size and there was release from PI by category-shift. This suggests again that succesful retrieval in recognition is also susceptible to PI and that PI may operates on retrieval of a "list pointer" rather than on individual items. This conclusion closely resembles the positional cuing view and suggests it to be valid across different paradigms.

The present study aims to test some further predictions from the positional cueing hypothesis with regard to PI. In particular, it investigates the effect of adding a prefix (i.e., the digit "8") to both of two successive lists, or to either the first or the second list only. The direct prediction of positional cuing theory is that PI will crucially depend on the similarity of the first item of successive lists, since the beginning of the list is decisive with regard to success or failure of direct access. The experimental task requires immediate recall of a single item, which is prompted by a positional probe immediately after list presentation. The probe indicates the serial position of the to-be-remembered (TBR) item and RT is the main dependent variable. The entire experiment is run in blocks of two successive trials -- a "non-PI" and a "PI" trial -- separated by ample intervals (see Turvey & Weeks, 1975). There are four types of trialblocks: (a) no prefix at either trial, (b) a prefix at both trials, or (c) one prefix only at the first, or (d) only at the second trial. In the control condition, in which no prefix occurs, neither in the first nor in the second list, an effect of PI is expected for all but the last few items of the list, similar to that observed by Sanders & Willemsen (1978). In the case of a prefix in both trials, the effect of PI will be magnified, particularly for the second and later items, since the strong similarity of the prefix item increases the degree of competition exerted by the first list when retrieving the second. When only one of the two trials contains a prefix, the first items of the two lists (a letter and a digit, or vice versa) are less similar than in the control condition (two letters). Therefore, in the conditions with a single prefix, it is expected that the effect of PI will be absent or at least much smaller than in the control condition. In all conditions, the items at the final SP's should not suffer from PI. They are retrieved through recency cues, that supposedly do not play a role in PI.

In contrast, acid-bath theory would predict that, because of a lack of similarity, a digit prefix in the first trial does not add to PI of a consonant list in the second trial. In this way, the acid-bath theory also explains the release from PI when shifting cognitive categories (e.g., Wickens, 1972). Hence, in the case of a prefix in both trials, PI should not differ from PI when only the second trial has a prefix, provided that the number of interfering consonants in the first list is the same. Similarly, when the PI trial has no prefix, PI should not depend on a prefix on the non-PI list, but, again, PI should only depend only on the number of interfering items. Finally, the acid-bath theory would also not expect PI on the final items, since some time is needed before items are affected by the acid.

Finally, an encoding theory of PI would predict a performance decrement in the second trial, irrespective of prefix conditions.

Chapter 5 Origin of PI

Method

Subjects and Task

Two male and 6 female subjects, between 19 and 25 years of age, participated in the experiment in groups of four at a time. They had no previous experience in STM tasks. Payment was on an hourly basis in addition to a bonus for each correct response in which RT did not exceed 2700 msec.

The task was immediate vocal recall of a single item from a list of successively presented visual items. The serial position of the requested item was indicated by a positional probe, i.e., the onset of one light from a horizontal row of lights. The utmost left light signalled the first item, the second light from the left signalled the second item, etc. Reactions to the probe should be as fast as possible, and errors few.

A subject was conveniently seated in a dimly illuminated, sound attenuated room and viewed a scope display (DEC, GT-40) at a distance of about 130 cm. A trial started with a 500 msec auditory warning signal (Sonalert, 2900 Hz, 65 dB) followed by a 1 sec interval whereafter a list of either five or six successive items was visually presented at a rate of 2 items/sec in the central area of the screen, which was marked by a fixation point. The actual number of items at a particular trial was indicated below the central area by a horizontal row of either five or six dots, which was presented together with the warning signal and remained on display until the end of the trial.

After presentation of the last item there was an interval of 500 msec followed by a positional probe signal. The probe consisted of a "cursor", i.e., a luminous square (3 x 2 mm) centered at one of the dots of the above mentioned horizontal row, thus indicating the SP of the TBR item. For each list type all SPs were probed with equal frequency.

Subjects were instructed to vocalize the items at presentation and to avoid any appreciable delay between presentation and vocalisation, in order to discourage them from grouping the items in sublists. In addition, they were asked to pronounce the items monotonously, without stressing any item or changing voice inflection. Throughout the experimental runs this was monitored by the experimenter.

All 5-letter lists and half of the 6-item lists consisted of capital letters, drawn without replacement from the consonant set F, J, K, L, N, P, R, T, Z. In the remaining 6-item lists the first item was a prefix (the character '8') which was followed by 5 consonant letters similarly drawn from the same set. Before delivery of the first item of a 6-item list subjects did not know whether or not the list would have a prefix as the first item.

Each subject was tested in blocks of two successive trials. Blocks were separated by an interval of about 4 min, which should suffice to eliminate proactive effects of previous blocks (Loess and Waugh, 1967). Consequently, the first trial of each block can be considered as a non-PI trial and the second trial as a PI-trial.

Experimental Variables and Design

The main experimental variables were (a) PI- vs. non-PI trials, i.e., the first or second trial of a trialblock, (b) the serial position of the TBR item, and (c) list type: 5 letters (5L), 6 letters (6L) and a prefixed list (PL). The prefixed list always consisted of a prefix and 5 letters. Five experimental conditions were defined as particular combinations of two list types (see left column of table 1). Each condition is labeled by two characters separated by a colon (:). The first character indicates list type on the first trial of the pair, the second character indicates list type on the second trial. Thus, condition 5:P means that a 5-letter list is followed by a prefixed list. Each condition consists of two trial types. A trial type is defined by its position in the pair of lists, by its own list type, and by the list type to which it is paired. The two trialtypes that constitute a condition are labeled by adding the suffix "-1" and "-2" to the condition label, the suffix indicating respectively the first and second trial (see middle and right column of table 1). Thus, trialtype 5:6 -1 and P:5 -2 refer to a 5-letter list, presented in a non-PI and a PI-trial, respectively, and in the context of a 6-letter list and a prefixed list, respectively.

The three list types (i.e., 5L, 6L, PL) all occur in non-PI trials, as baseline conditions that will permit the assessment of possible PI-effects. The 5-letter non-PI lists are followed either by 6-letter lists (in condition 5:6) or by a prefixed list (in condition 5:P). In addition, there is a condition 6:5. These conditions allow assessment of PI-effects in 5- and 6-letter lists, as well as a comparison of PI-effects in prefixed and 6-letter lists. A comparison between conditions P:5 and 6:5 investigates whether PI depends on the nature of the first list, while comparisons among 5:P, P:P and 5:6 are relevant

Table 1
Summary of Conditions, List types and Trial types.

Condition		First trial (non-PI)	Second trial (PI)
5:P	list type:	5L	PL
	configuration: a)	* * * * *	P * * * * *
	trial type: b)	5:P -1	5:P -2
5:6	list type:	5L	6L
	configuration:	* * * * *	* * * * * *
	trial type:	5:6 -1	5:6 -2
P:P	list type:	PL	PL
	configuration:	P * * * * *	P * * * * *
	trial type:	P:P -1	P:P -2
P:5	list type:	PL	5L
	configuration:	P * * * * *	* * * * *
	trial type:	P:5 -1	P:5 -2
6:5	list type:	6L	5L
	configuration:	* * * * * *	* * * * *
	trial type:	6:5 -1	6:5 -2

Notes: a): The character * stands for a letter item, P for prefix.
b): 5:P -1 indicates the first trial of condition 5:P, i.e., a 5-letterlist, which is followed by a prefixed list.

with regard to differential effects of single vs. double prefixes in a trial block.

Table 1 shows that the 5-letter lists as well as the prefixed lists occur twice in non-PI trials (i.e. in condition 5:P and 5:6, resp. in condition P:P and P:5). List types 5L and PL are each paired to two types of PI-trials. Therefore, the pooled data on 5-letter lists in non-PI trials will be referred to as 5L-1. Similarly, the pooled data on prefixed lists in non-PI trials will be referred to as PL-1.

The combinations in Table 1 are obviously not exhaustive but practical limits of the total number of trials dictated constraints. In choosing the list type combinations, the finding of Sanders & Willemsen (1978) was taken into account, that the number of items in the first list has no effect on the size of PI in the second list. For example, combination 5:6 and 6:6 can be assumed to evoke similar PI and thus only the first combination occurred as experimental condition. The relative frequencies of occurrence of the three types of list were equal in non-PI and PI-trials.

Procedure

Four subjects at a time participated in three daily sessions on consecutive days. Each session consisted of 90 periods of 5 min. In each period all subjects individually performed two successive trials, which lasted for about 45 sec. For each subject two consecutive trial pairs were always separated by a 4 min interval spent in leisure outside the experimental room. After completion of a trial pair, subjects were reminded, if necessary, of the pronunciation instruction and were informed about the correctness of their responses and whether their recall latencies fell within acceptable limits (between 90 and 2700 msec). Four breaks of about 30 minutes were interspersed in all sessions. All sessions lasted about 9 hours and were initiated for each subject by a warm-up trial pair.

On the day before the first session, subjects practiced an immediate serial written recall task in which 6-letter lists were auditorily presented at a rate of 2 letters/sec. The same consonants were used as in the experimental task. In addition, subjects were individually practiced on the experimental task by running an uninterrupted sequence of 30 trial pairs in which all experimental conditions were practiced.

In all sessions, different sequences of 90 pairs of letter lists were presented. All sequences had the following properties: (a) Each of the five conditions occurred 18 times, while these replications were pseudo-randomized, so that in each section of five consecutive trial pairs all conditions occurred once. (b) For all 6-item trial types, all SPs were probed 3 times per session; (c) For all 5-letter trial types, each SP was probed either 3, 4 or 5 times; (d) Over all 5-letter trial types, probe frequencies exceeding three occurred about equally often at each SP; (e) Over all conditions, the conditional probability of the second trial probe occurring at any SP - given a certain probed position in the first trial - was equalized as much as possible within a session.

Figure 1

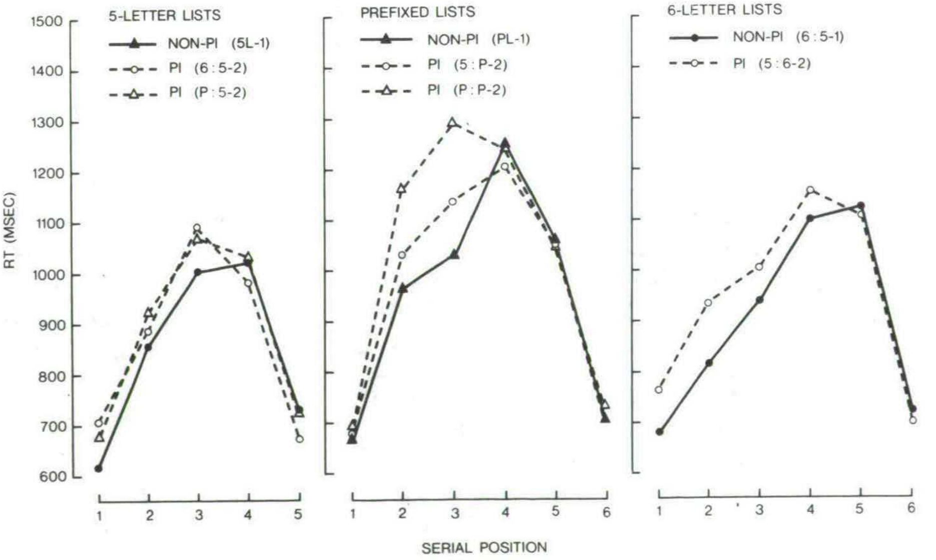

Figure 1: Median reaction times, averaged over subjects, as a function of serial position.

Results

Figure 1 presents mean RTs of correct recall, as a function of SP, averaged over subjects, and arranged according to list type in three panels; left: 5-letter lists (5L); middle: prefixed lists (PL) and right: 6-letter lists (6L). Only a few data, falling outside the RT range of 90-2700 msec, had to be excluded from analysis. The non-PI data of 5-letter lists were pooled (across the trial types 5:P-1 and 5:6-1) in one condition, termed 5L-1. Similarly, the data on prefixed lists in non-PI trials were pooled in condition PL-1 (pooling of trial types P:P-1 and P:5-1). Thus, in the analyses below, the pooled conditions 5L-1 and PL-1 represent the non-PI level of respectively 5-letter and prefixed lists. Table 2 presents average proportions of recall errors, for each trial type. All ANOVAs reported below are performed on individual mean RTs, unless stated otherwise.

Both RT and error rates are affected by SP and trialnumber (PI) in the same direction, suggesting that the RT effects are not due to speed-accuracy trade-off. In 5- and 6-letter lists, mean RT increases approximately linear over all but the last two SPs. A different pattern is observed for prefixed lists, where the slope over the first two SPs is substantially larger than for list types 5L and 6L. This is also reflected in pronounced error rates. In 5 and 6-letter lists, RT and errors increase in the second (PI-) trials as compared to the first (non-PI) trials. However, this effect is not observed at the last two SPs. The prefixed lists show a rather pronounced effect of PI in condition P:P, but the effect is restricted to SP 2 and 3: There is absolutely no PI effect at SP 1.

<u>PI-effects: early SPs vs. the last SP.</u>

A separate ANOVA was carried out for each list type, with SP and PI as variables. Only the first three and the last SP were analysed, as the remaining intermediate positions showed high variability within and between subjects. In all ANOVAs, the main effect of SP was significant (5-letter lists: $\underline{F}(3,21)=18.1$; Prefixed lists: $\underline{F}(3,21)=17.2$; 6-letter lists: $\underline{F}(3,21)=16.6$; $\underline{p}<0.001$). However, the main effect of PI was not significant for 5-letter lists, reached marginal significance for 6-letter lists ($\underline{F}(1,7)=4.4$, $\underline{p}=.07$) and high significance for prefixed lists ($\underline{F}(2,14)=11.8$, $\underline{p}=.001$). The SP x PI interaction showed a similar

Table 2

Proportion of errors averaged over subjects

PI-condition	Trial type	Serial Position 1	2	3	4	5	6
		Six-Letter Lists (6L)					
Non-PI	6:5 -1	.01	.08	.14	.15	.06	.00
PI	5:6 -2	.04	.07	.28	.21	.08	.01
		Prefixed Lists (PL)					
Non-PI a)	PL -1	.01	.08	.17	.21	.10	.00
PI	5:P -2	.03	.22	.17	.29	.10	.01
PI	P:P -2	.01	.22	.30	.18	.04	.00
		Five-Letter Lists (5L)					
Non-PI a)	5:L -1	.01	.12	.14	.08	.01	--
PI	6:5 -2	.00	.08	.23	.10	.04	--
PI	P:5 -2	.01	.17	.17	.14	.00	--

Note a: Averages over two trial types with identical non-PI trials.

pattern across list types: It was not significant in 5-letter lists, marginally significant in 6-letter lists ($\underline{F}(3,21)=2.5$, $\underline{p}=.08$) and significant in prefixed lists ($\underline{F}(6,42)=2.6$, $\underline{p}=.03$).

To further assess the observed SP x PI interactions, Post-hoc Newman-Keuls comparisons between PI-conditions were carried out at each SP. For prefixed lists, there were no significant differences at SP 1 among the conditions PL-1, 5:P-2 and P:P-2. However, at SP 2 and at SP 3, condition P:P-2 had significantly longer latency than conditions 5:P-2 and PL-1. The two latter conditions did not differ significantly at SP 2 and SP 3. At SP 6, none of the three comparisons showed a significant difference. For 6-letter lists, mean RT was significantly longer in the PI-trials for SP 1 and SP 2, but this was not the case for SP 6.

To check whether the marginal effects of PI for 6-letter lists were mainly due to the relative small effects at SP 3, a similar ANOVA was run on SP 1, SP 2 and SP 6. All main effects were significant (PI: $\underline{F}(1,7)=13.2$, $\underline{p}<.01$; SP: $\underline{F}(2,14)=16.5$, $\underline{p}<.001$) as well as the SP x PI interaction ($\underline{F}(2,14)=10.6$, $\underline{p}<.01$).

In short, the ANOVAs on early SPs and the last SP indicates a significant PI effect in the primacy part of 6-letter and prefixed lists, whereas a non-significant trend is observed for 5-letter lists. Secondly, the prefix is PI-resistent, regardless of the preceding list type. However, two prefixed lists in succession produce large effects of PI at SP 2 and SP 3, while these positions show only marginal PI when only the second list is prefixed.

PI-effects: early SPs only.

Since the above reported ANOVA on 5-letter lists failed to show an effect of PI, an additional SP x PI ANOVA was carried out for 5-letter lists, for SP 1, SP 2 and SP 3. There was marginal significance for PI ($\underline{F}(2,14)=3.4$, $\underline{p}=0.06$) and a significant effect of SP ($\underline{F}(2,14)=26.4$, $\underline{p}<.001$). The SP x PI interaction was not significant, indicating a constant effect of PI over the first part of the list. Scheffe's pairwise comparisons between the three 5-letter list types indicated that the weakly significant PI effect was mainly caused by the difference between non-PI lists (5L-1) and the 6:5-2 list ($\underline{F}(2,14)=2.8$, $\underline{p}=.09$). In contrast, the pairwise Scheffe tests involving trial type P:5-2 were far from significant. Thus, although the PI effect is not very substantial in 5-letter lists, it tends to be smaller when the preceding list contains a prefix.

To check whether PI effects are constant over early SPs, separate ANOVAs for prefixed and 6-letter lists were run for early list positions. For the 6-letter lists, SP 1 and SP 2 were analysed with PI as second variable. Both main effects were significant (PI: $F(1,7)=54.2$, $p=.001$; $F(1,7)=29.2$, $p=.001$), but the SP x PI interaction was not significant. The ANOVA on prefixed lists was carried out on SP 2 and SP 3, in the non-PI condition (PL-1) and in only one of the PI-conditions, i.e. P:P-2. Again, significant main effects for SP and PI were obtained (PI: $F(1,7)=20.5$, $p<.01$; SP: $F(1,7)=3.9$, $p=.08$), while theSP x PI interaction was not significant. Thus, the effect of PI is constant over the affected serial positions.

Comparison of the first vs. the last SP.

Figure 1 shows that for 5- and 6-letter lists, PI causes longer RTs at SP 1 but it does not affect the last position. This was substantiated in separate ANOVAs with SP (first vs. last) and PI as variables. For both 5- and 6-letter lists significant SP x PI interactions were found (5L: $F(2,14)=7.5$, $p<.01$; 6L: $F(1,7)=9.7$, $p=.01$). In contrast, no significant interaction was observed in the ANOVA on the prefixed lists.

For 5-letter lists, one-tailed t-tests between mean RTs at SP 1 and SP 5 showed that in non-PI trials RT at SP 1 was significantly shorter than at SP 5 ($t(7)=3.46$, $p<.01$), while in PI-trials there was no such difference. Apparently, PI annihilates the relative advantage of the first over the last SP. Figure 1 shows a similar trend for 6-letter lists. In the non-PI condition, mean RT at SP 1 was 43 msec shorter than at SP 6. However, a one-tailed t-test did not indicate significance. Conversely, in the PI-condition there was a 64 msec advantage of SP 6 over SP 1. This ifference was significant ($t=1.95$,one-tailed, $p<.05$).

Comparison of 6 letter vs. prefixed lists.

The effect of PI at SP 1 in prefixed and 6-letter lists was compared in an ANOVA, with PI and List type as main variables. The data of the prefixed PI condition were restricted to list type 5:P-2. Both main effects were significant (List type: $F(1,7)=5.9$, $p=.04$; PI ($F(1,7)=6.3$, $p=.04$). A significant PI * List type interaction was also found ($F(1,7)=8.9$, $p=.02$). In the non-PI condition, there was no significant difference in RT at SP 1 between the prefixed and the 6-letter lists ($\underline{F}$-test). Thus, in non-PI trials, the prefix is recalled as fast as the letter at SP 1. Furthermore, the analysis on SP 1 shows that the PI-effects are present in 6-letter lists, but not in prefixed lists. Hence, a prefix item from either a non-PI or a PI trial is equivalent to a "regular" first item from a non-PI trial.

Figure 1 shows that the slope over the first two SPs for prefixed lists is exceptionally steep as compared to the slope for 6-letter lists. An ANOVA at SP 1 and SP 2 in the non-PI conditions of prefixed and 6-letter lists indicated a weak significance of the SP x List type interaction ($\underline{F}(1,7)=4.9$, $\underline{p}=.06$).

Comparison of 5- vs. 6-letter lists.

Effects of PI at SP 1 and SP 2 were compared between 5- and 6-letter lists in an ANOVA, with PI, SP and List length as variables. The data of 5-letter PI-trials were restricted to trial type 6:5-2. All main effects were significant: SP: $\underline{F}(1,7)=45.1$, $\underline{p}<.001$; List length: $\underline{F}(1,7)=6.4$, $\underline{p}=.04$; PI: $\underline{F}(1,7)=43.9$, $\underline{p}<.001$. There were no significant first- or second-order interactions. Thus, at the first two SPs the effect of the PI is the same for 5- and 6-letter lists and there is an independent effect of List length in favor of the shorter list.

Discussion

The SP-curves for mean RT in the non-PI trials show the usual inverted-U shape, with a nearly linear increase over the first three or four SPs. These features support the idea of fast access to the first and the last item, and of a forward serial search for middle-of-the-list items.

Comparing recall latency between non-PI and PI trials indicates that PI prolongs recall latency but the effect is limited to the first few items. Error rates reflect the same trends as mean RTs. This essentially replicates the results of Sanders & Willemsen (1978).

In prefixed lists, there was no PI effect at SP 1 while there was a considerable effect at SP 2 and SP 3, particularly, in the case of a prefix in both trials. This effect was also considerably larger than for 6-letter lists. An encoding explanation of the PI effect, in terms of an attentional bias favoring acquisition of the first trial, is not tenable in view of the prefix effects. In non-PI trials recall of the prefix is as fast as recall of a first letter, which enables a direct comparison of the PI effects between prefix and letter item at SP 1. Apparently, in the non-PI trials the prefix is encoded, stored and retrieved as any other item. Yet, the prefix is not affected by PI, and hence, there is no evidence for an attentional decrement or less distinct encoding of the prefix in the second trial. Therefore, the PI decrements observed at SP 2 and SP 3 of the prefixed lists must have been caused by some other factor than encoding failure. Moreover, the augmented effect of PI observed in condition P:P is hard to explain with the encoding hypothesis. Why would the encoding of the second and third item in the second trial suffer <u>more</u> from a prefix than from a letter occurring in the first trial ?

If the first list did not contain a prefix, the PI effect on a prefixed second list was marginal and it did not differ significantly from a non-PI prefixed list (see figure 1, middle panel). Thus, the effect in prefixed lists depended on whether the previous list was also prefixed, suggesting "release from PI" when the first item in the two lists are from a different category.

These results strongly suggest that PI trials suffer in various degrees from genuine associative interference, leading to a longer search time and a higher error rate. Additional evidence in favor of this interpretation of the mean RT data is found in the error-rates. In the non-PI conditions very few errors occur at SP 1 and SP 6 in all list types. Moreover, there is a monotonic increase across SPs up to the penultimate condition. The error proportions in the PI-conditions corroborate the results on mean RT, in that they are higher in the PI than in the non-PI conditions.

However, the results are at conflict with acid-bath theory. In particular, this theory cannot explain the magnified effect of PI when both lists are prefixed (condition P:P), as compared to the condition in which only the second list was prefixed (5:P).

The effects of PI observed at SP 2 and SP 3 in prefixed lists confirm the predictions of positional cueing theory. The effects are either magnified in the case of a prefix in both lists, or PI is suppressed whenever the prefix is only present in the second list. This pattern of results can be well explained if one accepts the notion that access to the beginning of a prefixed list does not only depend on the positional primacy cue but also on the association between the prefix and the subsequent letter at SP 2. The association between the prefix and the second item suffers from competition from a similar association in the first prefixed list, causing PI in much the same way as the associations between the positional primacy cue and the first items of two lists. In other words, PI is transferred to the second item of the list by virtue of the episodic properties of the prefix that are similar to the positional primacy cue.

Thus, the P:P condition suffers more from PI since the prefixes of both lists increase the similarity of the lists and, hence, there is more competition from the first list. In contrast, there is some evidence for release from PI in the 5:P condition since the prefix now consitutes a unique auxiliary cue for accessing the second item, although the release is not complete. Another consequence is that the prefix itself is resistent to PI. Thus, in terms of Anderson & Bower's (1972) dual-process model of memory retrieval, these results suggest that PI affects the access-and-search processes (i.e., the "generation process") rather than the subsequent recognition process.

The effect of a prefixed list on a subsequent 5-letter list is only marginal (condition P:5). This is probably due to the fact that short lists are relatively insensitive to PI, as already observed by Sanders & Willemsen (1978) and as witnessed by the marginal significance of PI in condition 6:5. Hence, there is only a weak trend for release from PI in condition P:5. In 5-letter lists release from PI could only be demonstrated with marginal significance since the "normal" effect of PI in the sequence of two all-letter lists (condition 6:5) was somewhat smaller than expected. Yet, the joint evidence of modulation of the PI effect in 5-letter and prefixed lists allows the conclusion that the PI effect can be either "released" or magnified as a function of the similarity of the first item in two successive lists.

Two features of interest should be noted in comparing the SP-curves of prefixed and six-letter lists in the non-PI trials. First, mean RT is equal for the prefix and the first letter-item: A "known" and an uncertain item are recalled with equal speed and accuracy. Apparently, recall at SP 1 is not affected by any categorical distinctiveness of the first item, which suggests similar ease of access to both lists by means of the primacy cue. Secondly, there is a significant greater increase in the RT-curve from SP 1 to SP 2. This suggests a weaker inter-item association in case of a digit-to-letter transition, which is due to weaker pre-existing associative bonds between items from different cognitive categories. This is in line with the study by Sanders & Schroots (1968), showing that such transitions within a list seriously impair ordered recall as more remote categories are involved. The effect of this transition is also reflected in the relatively high error-score (0.22) at SP 2 in the PI-condition for prefixed lists. In conclusion, the observed transition effect in prefixed lists support the notion of forward serial search, in which the first item serves as a retrieval cue for the second (letter-)item.

By way of summary, it seems fair to conclude that the present study does not support encoding or storage theories of PI, but that it confirms the main predictions of positional cueing theory, for two main reasons: (a) effects of PI are constant over and restricted to the first part of the list. This implies that PI affects the primacy access, rather than the subsequent search process. (b) Effects of PI may increase or decrease as a function of the degree of similarity of the first item of the non-PI and PI list. The prefix item provides an auxiliary primacy cue and thus it increases or diminishes the discriminability of access to the PI list, depending on whether or not both lists are prefixed.

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CHAPTER 6

SHORT-TERM PROACTIVE INTERFERENCE REVISITED

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Chapter 6

Abstract

The basic experimental task consisted of memorization of a list of consonants followed by positionally probed recall of a single item. Immediately after presentation of a list, a positional probe was presented indicating the serial position (SP) of the requested item. Response latency was the main dependent measure. Previous studies with this paradigm have shown that, if many trials are run in close succession, the latency for the most recent SP is smaller than for the first SP, whereas the reverse is found when trials are given in relative isolation. The hypothesis is tested that this effect reflects a buildup of proactive interference (PI) over successive trials. Subjects received strings of 6 closely spaced trials and the effect of successive trials on RT was measured. In line with the common findings on PI in short-term recall, the main effect of PI occurred at the second trial of a string, without any clear effect at later trials. Hence, the relatively strong recency effect as observed with many closely spaced trials seems not to be due to PI but to a more aspecific change in resource allocation to the various parts of the list.

In short-term serial recall, performance rapidly declines across trials, due to proactive interference (PI) from preceding trials (e.g., Keppel & Underwood, 1962). PI builds up as a negatively accelerated function across trials, the bulk of PI stemming from the one or two immediately preceding trials. Furthermore, the buildup appears to depend on temporal proximity: There is no PI when two trials are separated by an interval longer than 2 min (Loess & Waugh, 1967).

Most studies on short-term PI have employed the so called Brown-Peterson paradigm, in which a consonant trigram is recalled after a filled retention interval. Yet, PI is also observed in the response latency of positionally probed vocal recall of a single item (Sanders & Willemsen, 1978). In this paradigm, a list of items is followed by a positional probe, indicating the serial position (SP) of the requested item. Usually, response latency is the dependent measure. This paradigm avoids effects of output interference and, moreover, latency may provide a more sensitive measure of PI than probability of correct recall.

Sanders & Willemsen (1978), observed that in positionally probed recall, only the first items in the list were vulnerable to PI. In their study, two trials were presented in close succession and trialpairs were separated by a longer interval during which PI could dissipate. Thus, the task consisted of alternating non-PI and PI trials (Turvey & Weeks, 1975). Reaction times (RT) for the first few items of the list increased in the second trial as compared to the first trial. The results of Sanders & Willemsen comply with PI effects in free recall (Craik & Birtwistle, 1971). Sanders & Willemsen (1978) also found that, in the first trial of a pair, RT to the final item of a list was longer than to the first item, whereas in the second trial these positions had about equal latencies. This change from a primacy advantage in "non-PI" trials to about equal latencies in "PI trials" was replicated by Hendrikx (Note 1), again in a setting in which two trials were run in close succession, followed by a longer interval before presenting the next pair. However, in the case of many successive trials, (Hendrikx (1984a; 1984b) repeatedly found a substantial faster RT for the most recent item as compared with RT for the first item, the difference amounting to about 200 ms. This could suggest that the effect of PI on recall latency acccumulates over a larger number of trials than indicated by the traditional measures of recall accuracy.

Therefore, in this paper, we investigate the buildup of PI within strings of 6 closely spaced trials. Latency of vocal recall was measured in response to a positional probe. Successive strings were separated by longer intervals, allowing for dissipation of PI. The primary question is whether PI continues to build up across trials within a string. PI effects are assessed as a function of trial number, that is, the position of the trial within a six-trial string. The first trial of each string is regarded as free from PI, whereas the second and later trials may increasingly be affected by PI originating from preceding trials (see Turvey & Weeks, 1975). As a result, faster RT to the first item may gradually change, across trials, into faster RT to the final item.

In addition, effects of list length (LL) and previous list lengths (PLL) were examined. Following the "acid bath" theory of PI (Posner & Konick, 1966), vulnerability of the recall of the first item to interference from a previous list may increase as the present list grows longer, since the retention interval grows longer. In the same vein, a larger length of the preceding list(s) adds to the "concentration of the acid", resulting in a stronger PI effect. The acid bath theory considers PI as an effect on storage. Alternatively, PI may be due to confusion at retrieval. For example, positional cueing theory (Sanders, 1975), explains PI in terms of confusion between cues of successive lists which provide access to the first item. Hence, positional cueing theory does not predict more PI with a longer LL or PLL. Indeed, Sanders & Willemsen (1978) did not observe an effect of either PLL or LL in the case of only one prior interfering list. The present use of six-trial strings could provide a more powerful test between the notions of acid bath and positional cueing theory, in particular if PI would accumulate across 6 trials.

Method

Subjects and task

Two groups of 4 students of Tilburg University served as subjects. the subjects had no previous experience in memory experiments and were paid a fixed amount and an additional bonus for each correct response. The task was immediate vocal recall of a single item from a list of either 4, 5 or 6 successively presented visual items. The serial position (SP) of the requested item was indicated by a positional probe, consisting of the onset of a light from a horizontal row of lights. Subjects were asked to respond to the probe should be as quickly and as accurately as possible. Subjects vocalized the list in synchrony with presentation. They were asked to vocalize the items at presentation, without stressing or changing voice inflection. This was monitored by the experimenter.

In a trial, a list of consonant letters was visually presented at a rate of 2 letters oer second, followed by a 500-ms interval and a subsequent probe signal. The probe was a light at one of the locations in a horizontal row of 4, 5 or 6 dots, the number of dots corresponding to the number of items in the current list. The dots respectively indicated, from left to right, the first through last item of the list, so that the location in which the probe occurred indicated the SP of the requested item. Successive trials within a string were separated by a 3-sec interval. Subjects performed individually in strings of 6 closely spaced trials. To allow for dissipation of PI, a pause of 4.5 min intervened between successive strings; subjects spent the time in leisure outside the experimental room.

A subject was seated in a dimly-lit sound-attenuating room, viewing a scope display (DEC, GT-40) at a distance of about 1.3 m. A trial started with a 500 ms auditory warning signal (2900 Hz, 65 dB) and a 1-sec interval, after which a list of either 4, 5 or 6 successive capital letters was presented in the centre of the screen, marked by a fixation point. The actual number of items at a particular trial was indicated below the center by the horizontal row of 4, 5 or 6 dots. The dots were presented together with the warning signal and remained on display during the trial. After presentation of the last item there was an interval of 500 ms followed by the positional probe. The probe consisted of a cursor (a luminous square of 3 x 2 mm) centered at one of the dots in the horizontal row. For each LL, all SPs were probed with equal frequency.

Design and procedure

The variables list length (LL), serial position of the probe (SP), trialnumber (N) and length of the immediately preceding list (PLL) were varied orthogonally within subjects in a 3 x SP x 6 x 3 design (SP range depending on LL).

Four subjects at a time participated in three consecutive daily sessions. Each session consisted of fifty 6-min periods during each of which all four subjects performed individually and in a fixed order, in a string of 6 trials. Thus, each subject participated over three days in a sequence of 150 strings of 6 trials each. Each subject received a different order of the same 150 strings. In each session, a 30 min pause interrupted the procedure after the 12th, 24th and 36th string. LL was pseudo-randomly assigned to trials within strings.

After completion of a trial pair, a subject was informed about the correctness of recall and whether RT fell within acceptable limits (90 - 2700 ms). The day before the first session, subjects practiced immediate serial written recall of 6-letter lists, spoken at a rate of 2 letters per second. The same consonants were used as in the experimental task. Subjects also had 30 trials of practice on the actual experimental task.

Materials

All lists consisted of a pseudo-random sequence of capital letters, drawn without replacement from the consonant set F, J, K, L, N, P, R, T, Z. The frequency of the consonants was counterbalanced over SPs and all consonants were probed with about equal frequency. This was done separately for each combination of list length and trialnumber. For the second group of 4 subjects, the letter composition of the lists was changed systematically by a one-to-one replacement of each letter within the set.

Lists of 4, 5 and 6 letters occurred respectively in 40, 50 or 60 trials at each trialnumber. Thus, for each trialnumber the proportion of trials with a given list length was fixed at respectively 0.27, 0.33 and 0.40. In addition, LL was assigned to trials so that the conditional probability of receiving a certain list length at given trial, given any previous list length, was always equal to the above mentioned over all proportions.

Results and discussion

The ANOVAs reported below were performed on individual median RTs of correct recall. Effects of PLL were absent, as shown in ANOVAs on the first three SPs, run separately for each of trial 2 to 6. Factors were LL (4,5,6), PLL (4,5,6) and SP (1,2,3). In each ANOVA, there were only significant main effects of LL (df=2,14; p=<0.05) and of SP (df=2,14; p<0.001). The PLL-effect did not reach significance, either as main effect or in interactions. Hence, data were collapsed across PLL-levels. In all conditions, recall error were quite infrequent and not analysed.

All SP-curves for median RTs showed the familiar inverted-U shape. Figure 1 shows means of individual median RTs for the first and last SP

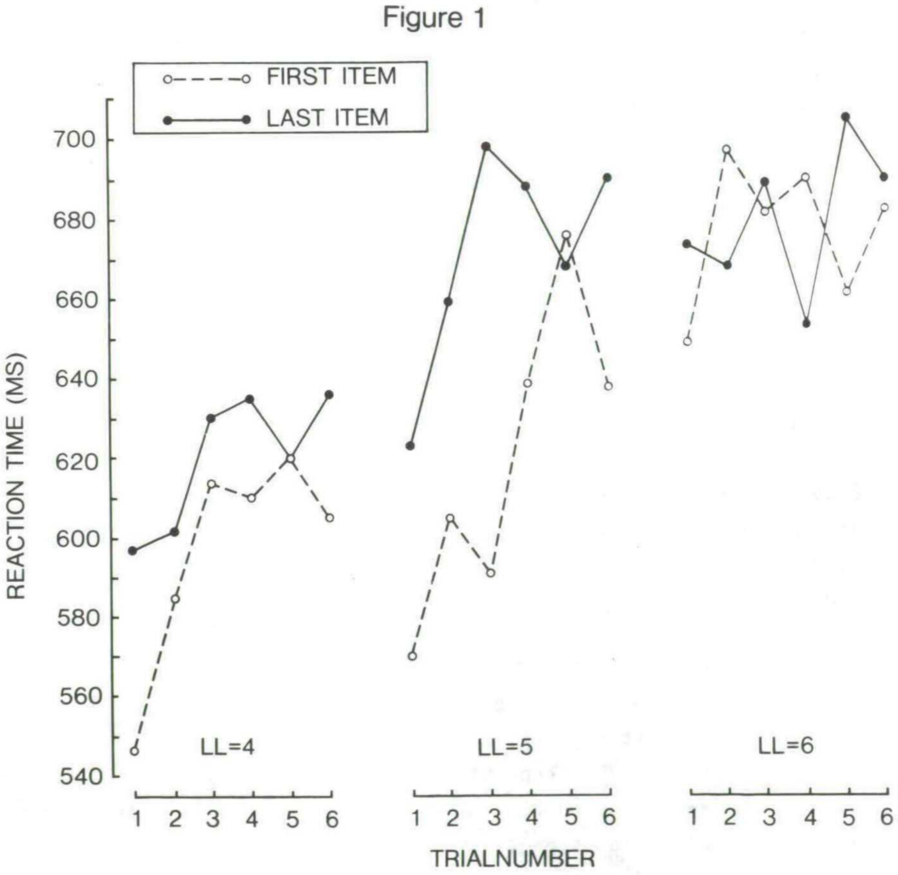

Figure 1: Means of individual median RTs of the first and last serial position (SP) as a function of trialnumber and list length (LL). First SP: Open circles, dashed lines; Last SP: Filled circles, solid lines.

as a function of trialnumber. In particular for lists of 4 or 5 items, there was at the early trials a smaller latency for the first item, as compared with latency for the final item, an effect which disappeared at later trials. An advantage for the final item was not observed in any part of the trial string. An ANOVA was run separately for each list length on the first and last SP, with SP and Trials (1-6) as factors. The main effect of SP was not significant, but there was a significant effect of Trials for LL 4 and LL 5 ($F(2,35)=5.1$, $p=0.002$; $F(2,35)=6.2$, $p<0.001$, respectively). For LL=5, the SP x Trials interaction was also significant ($F(5,35)=2.6$, $p=0.04$). Although there was a similar trend at LL 4, there was no significant interaction for LL 4, nor for LL 6 ($F(5,35)=0.8$, and, 1.9, respectively).

Figure 2 shows the differences in median RT between each of the later trials and the first trial of the six-trial strings, calculated separately for the pooled prerecent items and the last two items. These differences can be used to assess PI. The latter type of difference should reflect trial effects <u>un</u>related to PI. PI is reflected in the generally greater difference score for prerecent items observed across all trials, suggesting that the major effect of PI occurs at the second trial. In addition, there is a general trend toward an increase of the differences across trials, which suggests that not all trial effects are related to PI. An ANOVA was run, separately for each list length, on individual differences between later trials and trial 1, with Trials (2-6) and List part (prerecent vs. last two items) as factors. For LL=5, the effect of Trials was significant ($F(4,28)=5.9$, $p=0.002$) whereas the effect of List part was only marginally significant ($F(1,7)=3.8$, $p=0.08$). However, for LL 6 and LL 4, there was no significance for the main effects and the interaction. Since PI effects were rather small, the present data do not allow a rigid test of whether (previous) list length affects the size of PI.

In summary, we obtained no evidence for a continuing PI buildup in the primacy part of the list that could account for the faster RT for the most recent items as compared to the first item, as observed at long series of trials. Also, previous list length does not affect PI, which confirms the results of Sanders & Willemsen (1978). It appears that a global task feature, such as massed <u>versus</u> spaced trials, causes a substantial change in relative performance between list parts which is not due to PI but to a shift in attentional bias favoring, respectively, the last or the first part of a list. In analogy with Hockey, MacLean &

Hamilton (1981), prolonged task execution may be a stressor that changes the balance of resources for underlying component processes. For example, with massed trials, acquisition of new input may improve at the cost of reduced storage, causing a trade-off in performance between the first and last part of a memory list.

Figure 2

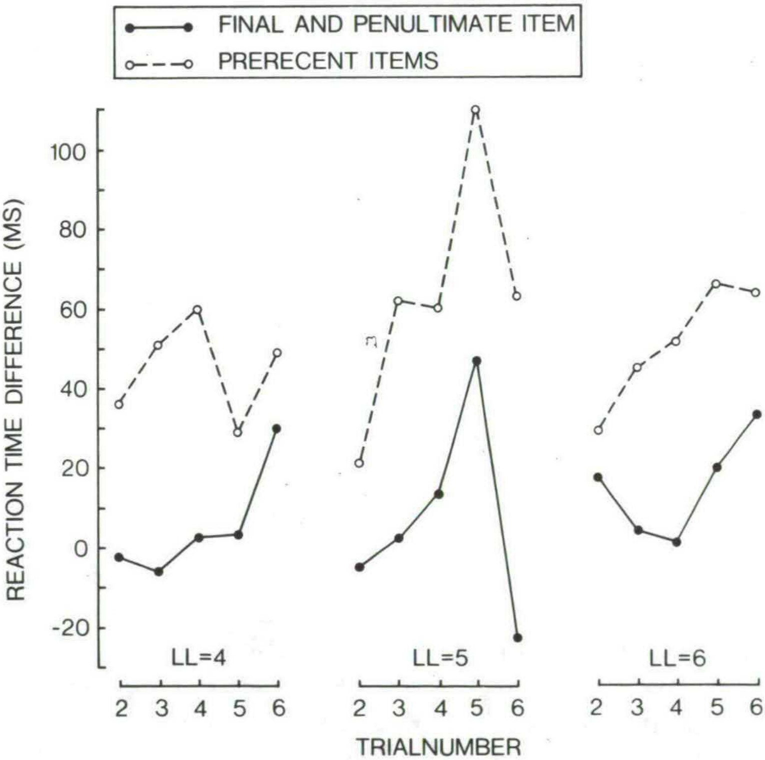

Figure 2: Difference in median RTs between a later trial and the first trial, as a function of trialnumber and list length (LL), for the pooled early SPs (open circles, dashed lines) and the last two SPs (filled circles, solid lines).

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CHAPTER 7

EFFECTS OF GROUPING AND PRECUEING ON MEMORY SEARCH

Chapter 7

Abstract

Subjects were asked to decide whether or not a probe item matched an item from a recently presented memorized list, consisting of either 2, 4 or 6 items. Reaction time (RT) to the probe was measured as a function of list length (set size) and as a function of serial position (SP) of the matching item in the memory list. In a grouping condition, the memory lists were temporally structured by inserting a pause during the successive visual presentation of the items. In a cueing condition, one of the temporally defined sublists was precued, so as to indicate that a match could only occur in the precued sublist. Linear and parallel set-size functions were found for positive and negative probes. Grouping substantially decreased the intercepts, but not the slopes of the set-size functions. Cueing enhanced the beneficial effects of grouping, but only for positive probes. Pronounced effects of SP were found in six-item lists, with a primacy and a recency advantage. Grouping and cueing affected the SP-curves in a complex way, depending on the particular temporal structure. It was argued that these findings neither support self-terminating or exhaustive serial-search models of item recognition, nor parallel-search models. Instead, a direct-access model provides an adequate account of the present findings.

Chapter 7 Recognition Memory

In a Sternberg memory-search task, subjects decide whether or not a probe item matches one of the items of a recently memorized list (Sternberg, 1969). It is commonly found that reaction time (RT) for a yes-no decision increases linearly with the number of memorized items (set size), at a typical rate of 30 to 40 msec/item. Another usual finding is that set-size functions have about equal slopes for positive and negative probes (i.e., for probes that either match or do not match an item from the memory set). This led Sternberg (1966, 1969, 1975) to the suggestion that memory search is serial and exhaustive, that is, one memorized item is compared at a time with the probe and the search proceeds until all items of the memorized list have been processed, regardless of whether a match occurs during search. Presumably, only items from the memorized list are searched.

The major alternative serial model proposes a self-terminating search as soon as a match occurs. Assuming that search is limited to the memorized items, this model predicts that the slope of the set-size function for positive probes equals half of the slope for negative probes, since the search would stop at a match after comparing, on the average, half the number of items in the memory set. Theios, Smith, Haviland, Traupmann & Moy (1973) have argued that a self-terminating serial model can also explain the observed parallel set-size functions for positive and negative probes, if it is assumed that the search is made through a memory buffer in which items are ordered as to search priority. The buffer also includes items that do not occur in the memorized list, such as items from previous lists. Thus, the search always terminates upon a match, but since the matching item may not have occurred in the memorized list and thus, the match may evoke a negative response. Unless stated otherwise, this paper considers only this version of the self-terminating model (see also Atkinson, Herrmann & Wescourt, 1974).

The main difference between the exhaustive and self-terminating model is concerned with the assumption that search continues after a match. Clearly, when searching for a possible target embedded in non-targets, there should be some economical stopping rule to restrict the search domain.

Grouping

The present study attempts to test between the exhaustive and the self-terminating serial model by a temporal grouping of the list, through inserting a pause in between the presentation of two items. It is argued that a pause constitutes a logical termination point for exhaustive search, at least when a match has occurred in the sublist that is searched first. In that case, grouping would reduce recognition RT to the level observed with a list length (set size) equal to the sublist (see footnote). The exhaustive model also predicts no grouping advantage for negative probes, since this requires search of both sublists. (See table 1 for a survey of the predictions.) In contrast, a self-terminating model does not predict sizeable grouping effects, since grouping will not affect the point of search termination.

Temporal as well as subjective grouping of items has been shown to improve speed and accuracy of short-term recall, in particular for items at a group boundary (DeRosa & Baumgarte, 1971; Ryan, 1969 a, b; Hendrikx, 1984 a). The question is whether grouping affects recognition and whether current theories on recognition memory can accomodate grouping effects. Burrows & Okada (1974) found an adverse grouping effect in short-term recognition; they suggested that a pause acts as an additional item, increasing the duration of search. Their study also suggests that search is exhaustive in the sense that subjects did not respond to the logical termination point provided by the pause. To check this result, the present experiment partly replicates Burrows & Okada's (1974) study.

The exhaustive model allows quantitative predictions about the size of the grouping effect. For example, the expected average gain from grouping is 30 msec for four-item lists, divided into two equal sublists, and 40 msec for a six-letter list, divided into a

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Footnote: The maximal size of the grouping effect for positive probes should be positively related to the number of items in the discarded sublist. However, the actual size depends on the subject's strategy as to the order in which the sublists are searched. In the extreme case of an absolute bias for one sublist, the effect is maximal for matches in that sublist and zero for the remaining sublist(s). Hence, the average grouping effect over the entire list is always positive.

Table 1

Effects of Grouping and of Cueing, as predicted by Self-terminating and exhaustive serial-search models.

	Exhaustive Search		Self-terminating Search
	probe type:		
	positive	negative	both probe types:
GROUPING	RT reduction	no effect	no effect
	both probe types:		both probe types:
CUEING	RT reduction inversely related to the size of the cued subset. The effect should be twice as large as with uncued grouping.		RT reduction, possibly larger for negative probes

Note: The predicted effects are relative to an ungrouped and uncued control condition.

four-item and a two-item sublist (assuming a search rate of 30 msec/item; See Appendix).

There may be an additional positive effect of grouping due to improved encoding of items at the sublist boundary. This could facilitate the comparison process for boundary items during search. Such an encoding effect might occur irrespective of exhaustive or self-terminating serial search and the effect should also occur for negative probes. However, Hendrikx (1984, a) did not find evidence for encoding benefits as a result of grouping on latency of single-item recall in response to a positional probe, using virtually the same presentation technique as in the present experiment. This will be further considered in the discussion.

Precueing

As a further test between exhaustive and self-terminating serial search, the present experiment investigates effects of precueing one of the temporally defined sublists briefly in advance of the probe. The cue indicates that whenever the probe is positive, the match with a memorized item only occurs in the cued sublist. Precued sublists always corresponded to the temporal structure imposed on the list, so that the cue condition investigated the joint effect of precueing and grouping. Unless stated otherwise, precueing effects are assessed relative to an uncued and ungrouped control condition, rather than to the (uncued) grouping condition. (In this paper, the terms cueing and precueing are interchangeable.)

Within the context of exhaustive serial search, the cued sublist provides a logical termination point for the search process, even if the probe is negative, since a match cannot occur in the uncued list. Hence, the exhaustive model predicts a grouping advantage for negative probes, but only if a sublist is cued (see table 1). Positive probes should always benefit from grouping, but more so with additional precueing of a sublist under the obvious assumption that the cued sublist is searched first. In fact, the precueing effect is predicted to be twice the grouping effect (see Appendix) and the size of the precueing effect should be positively related to the size of the uncued sublist, for both positive and negative probes.

The self-terminating model also predicts a positive effect of precueing, to the extent that the items occurring in the uncued sublist can be discarded from the memory buffer and, hence, from memory search.

The cueing advantage should be at least equivalent for positive and negative probes, or possibly larger for negative probes: The negatives should occupy less prominent positions in the memory buffer. As a consequence, negative probes could benefit more from cueing than positive probes, since the discarded items from the uncued sublist tend to occupy more prominent positions.

Anticipating the results of the experiment, it is noted that the predictions of neither serial model fitted the results. This led to the consideration of alternative explanations in terms of parallel models and direct-access models of short-term recognition (e.g., Ratcliff, 1978), which will be elaborated in the discussion.

Method

Experimental tasks

The experiment had three main types of conditions: Control conditions, in which lists had no temporal structure, and grouping and cue conditions, where lists were always temporally structured. In the control conditions, lists had either 2, 4 or 6 different letters that were visually and successively presented, at a rate of 600 msec/item. Subjects vocalized the items in synchrony with their presentation and without voice inflection. Throughout a trial, a horizontal row of dots of the same length as the list was visible. The dots were a spatial representation of the temporal positions of the list. One sec following list presentation a 500-msec control signal was presented, consisting of a row of cursors appearing above the dot row. The number of cursors equalled the number of dots and the number of items in the list. 200 msec after termination of the control signal, a probe letter was presented in the center of the screen for 800 msec. Subjects pressed one of two keys depending on whether or not the probe matched one of the letters in the list. The row of cursors merely served as a temporal warning for the testletter.

The grouping condition and the cue condition had only 4- and 6-letter lists which were temporally structured. A 600 msec pause occurred between the 2nd and 3rd letter in the case of 4-letter lists, or, in the case of 6-letter lists, between the 4th and 5th letter. Subjects adapted to this structure while reading the list during presentation. Trials from the grouping and cue condition were randomly mixed at presentation.

In the grouping condition, the entire row of cursors preceded the testletter, in the same way as in the control condition. Hence, the grouping condition only differed from the control condition in temporal structure of the list.

In the cue condition, the test letter was preceded by a subset of cursors, pointing to certain SPs and coinciding with one of the sublists as defined by the temporal structure of the list. The subset of cursors had the same timing as the row of cursors in the control and grouping condition. In this way, subjects were cued with respect to which part of the list would contain the target letter in case of a positive trial, so that the remaining (uncued) sublist became irrelevant to the task. Untill the occurrence of either the cue or the control signal, subjects were not informed about whether the trial would be run under the control condition or the cueing condition. However, temporal structure and list length were signalled at the beginning of each trial. Subjects were explicitly informed about the significance of the cue and were encouraged to improve their performance by using the cue.

Stimulus materials

The 6-letter lists were composed pseudo-randomly from the 15-consonant set. With some minor deviations, each consonant occurred four times at each SP. One half (30) of the 6-letter lists contained a "positive" letter (i.e., matching the probe). The positive items were assigned in such a way that 5 different probes were matched at each SP. In addition, all 15 consonants occurred twice as positive items across the positive lists. To the remaining 6-letter lists (30), negative items (i.e., not matching the probe) were assigned. The negative items were taken from the 15-consonant set, in such a way that all 15 consonants occurred twice as a negative item across these lists. This type of list will be referred to as ABCDEF.

The 4-letter and 2-letter lists were constructed by selecting 4- and 2-letter sections from the 6-letter lists. For the 4-letter lists, the 6-letter lists were used in which a match occurred at SP 1, 2, 5, or 6. These lists were reduced to section ABCD for a match at SP 1 or 2, or to section CDEF for a match at SP 5 and 6. Hence, a positive 4-letter lists always matched a section of a positive 6-letter list. This principle insured that the same positive items were tested with different list lengths, but in the same context. The negative 4-letter lists were randomly chosen from sections of the negative 6-letter lists.

One half of these 4-letter lists consisted of section ABCD, the other half consisted of section CDEF.

The 10 positive 2-letter lists were similarly designed, i.e, by selecting sections AB or EF of the positive 4-letter lists. The 10 negative 2-letter lists were drawn from the remaining negative 6-letter lists, again reduced to section AB or EF.

The structured lists were derived from the unstructured lists by inserting a pause between two specific letter positions, thus creating for respectively list structure 2-4 and 4-2, the list type AB-CDEF and ABCD-EF, and for structure 2-2 the list types AB-CD and CD-EF.

The same procedure of deriving 4- and 2-letter lists from 6-letter lists was also applied to the reversed set of 60 6-letter lists, which will be referred to as list type FEDCBA. This was done to minimize letter-specific effects of probes, as well as the effects of well-known acronyms and possible ideosyncrasies within lists. An entire new set of lists was created by reversing the order of letters within the original 6-letter lists, without changing the matching letters. In this way, each matching letter in list type FEDCBA matched at an SP that was mirrored with respect to list type ABCDEF. This also produced 4-letter lists of the type FEDC and DCBA, and 2-letter lists of the type FE and BA. In addition, reversed structured lists were derived.

Two groups of subjects received a different combination of original and reversed lists. For group 1, the control condition was run with the original lists (i.e., of the type ABCDEF or sections thereof, while group 2 received (sections of) list type FEDCBA. In the grouping and the cue condition, both groups received different combinations of original and reversed list types. To reduce repetitive presentation of identical letter combinations, subgroups (A and B) of each group received different sets of structured lists in the grouping and cue condition. For instance, the subgroups 1-A and 2-A received grouped lists of type AB-CDEF and FEDC-BA, while the subgroups 1-B and 2-B received list types FE-DCBA and ABCD-EF.

Procedure

In the control condition subjects received 60 trials with 6-letter lists, 40 trials with 4-letterlists and 20 trials with 2-letter lists. For each list length, half of the trials were positive. The control condition was run in a block of 120 trials with randomized list lengths.

In both the cue and grouping condition 60 trials were presented for both list structures 2-4 and 4-2, while there were 40 trials for list structure 2-2. For each list structure, half of the trials were positive, matching 5 times with a different list letter at each SP. Both grouping and cue condition were run in altogether 320 trials, divided into three trialblocks, each consisting of a random sequence of conditions, list lengths and list structures.

Each subject participated in the experiment on two consecutive days. Sessions were always separated by 30-min pauses. Each session generally lasted 30 min and consisted of two blocks of trials, separated by a 2-min pause. To prevent subjects from adopting grouping strategies, the control condition (employing unstructured lists) was always run on the first day, prior to the grouping and cue condition. Since this design entails the danger that effects of practice may differentially affect conditions, extensive practice was given before the actual measurements were taken: On the first day, each subject received 20 control trials during instruction and one practice session, consisting of two blocks of 60 control trials, followed by the experimental session in the control condition. Each trialblock consisted of 60 trials preceded by 2 warm-up trials. After completion of the control session, subjects received instruction on the task with the structured lists (i.e., grouping and cue condition), and one block of 60 practice trials with the structured lists. The grouping and cue condition were run on the second day, in blocks consisting of 64 trials, preceded by 2 warm-up trials. First, each subject had one additional block of practice trials, followed by 2 sessions of 2 trialblocks each and one session with one trialblock. The cueing factor as well as set size were randomly mixed across trials within trialblocks, to prevent effects of changes in recognition criteria, as demonstrated by Ratcliff (1978) in blocked presentation designs.

Figure 1

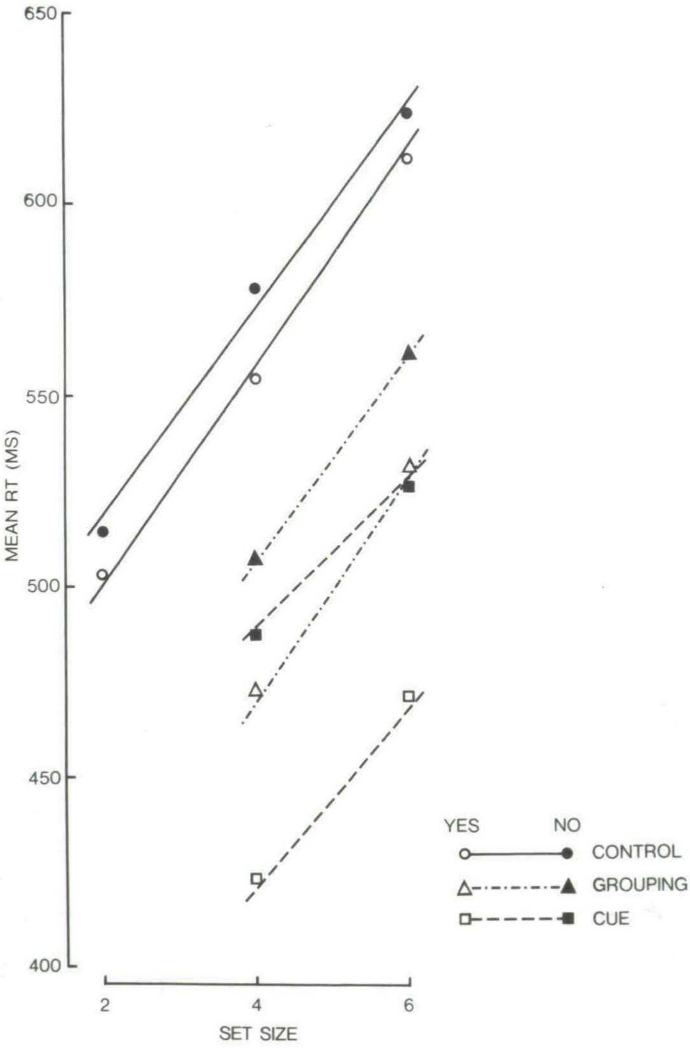

Figure 1: Mean correct reaction time (RT) as a function of set size, in the control condition (circles), the grouping condition (triangles) and the cueing condition (squares). Open symbols: positive trials; Filled symbols: negative trials. The linear functions are specified in table 2.

Results

Figure 1 presents mean RT of correct responses as a function of set size, separately for positive and negative trials (trial type) and for the control, grouping and cueing conditions. The means are averaged over serial positions and subjects. For the six-letter lists (set size 6), the means are calculated on the pooled data of list structure 2-4 and 4-2. table 2 presents error rates and linear set-size functions, fitted by means of linear regression (least-squares method). Error rates are moderate, except in the control condition, and tend to be positively related to correct mean RT, which argues against speed-accuracy trade-off. Error rates are smaller in negative trials. Only correct responses were further analysed.

Figure 1 shows rather substantial effects of grouping and cueing, relative to the control condition. As a check on the possible effect of practice that may have contributed to this effect, mean RT for six-item lists were calculated separately for each of the four trialblocks in the control condition (run on the first day) and for each of the five trialblocks in the grouping condition (run on the second day). Performance stabilized in the control condition after the second block (mean RT across trialblocks was, respectively, 741, 643, 617 and 608 msec). Therefore, only the two last blocks were further analysed. Performance in the five trialblocks in the grouping condition was also stable: Mean RT across trialblocks after practice trials was, respectively, 555, 550, 547, 546 and 528 msec. Hence, the large grouping and cueing effects cannot be due to prolonged practice, and the five blocks of trials contributed the results on the grouping and cueing condition. Yet, the stability of performance across trialblocks does not exclude effects of dissipation of reactive inhibition between successive days. However, since it is commonly found that regular 30 min breaks between blocks of trials suffice for dissipation, large effects of dissipation between days seem to be precluded. Nevertheless, differences in general performance levels between control and experimental conditions must be interpreted with some care.

All ANOVAs reported below were performed on individual mean RTs unless indicated otherwise. A 3x2 ANOVA was performed in the control condition, with factors List length (2,4,6) and Trialtype (positive vs. negative). For positive trials, means were pooled across serial

Table 2

Mean RTs, error rates and linear set-size functions for positive and negative probes and for each set size and condition.

	Set size 2	Set size 4	Set size 6	Set-size function
CONTROL				
negative	[2.5] 515	[2.9] 578	[3.0] 624	RT= 463 + 27N
positive	[5.8] 503	[3.7] 554	[6.9] 612	RT= 443 + 28N
pos. - neg.:	12	24	12	
GROUPING				
negative	-	[1.9] 507	[3.7] 561	RT= 398 + 27N
		+71	+63	
positive	-	[3.3] 473	a) [9.8] 531	RT= 349 + 30N
		+81	+81	
pos. - neg.:		34	30	
CUEING				
negative	-	[0.6] 487	[4.7] 526	RT= 409 + 20N
		+91	+98	
positive	-	[2.0] 423	[5.0] 471	RT= 324 + 24N
		+131	+141	
pos. - neg.	-	64	55	

Notes: Error percentages are in brackets. Mean RTs and differences are in msecs. Values prefixed with + indicate a grouping or cueing advantage, relative to the control condition.

a) The relative high error percentage of 9.8 was due to list structure 4-2, with 12.8% for positive probes and 2.8% for negative probes. For structure 2-4, the values were 6.9 and 4.1%, respectively.

positions (SPs) of the item matching the probe. The main effect of List length was significant ($F(2,22)=36.5$, $p<0.0001$). Neither the main effect of trialtype, nor the first-order interaction was significant, indicating essentially identical slopes and intercepts for the positive and negative set-size function in the control condition.

In order to compare among Conditions (i.e., control vs. grouping vs. cue condition) a 3x2x2 ANOVA was performed on RTs pooled across serial positions, with factors Conditions, List length (4,6) and Trialtype. All main effects were significant; Conditions: $F(2,22)=24.8$, $p<0.001$; List length: $F(1,11)=104.4$, $p<0.001$; Trialtype: $F(1,11)=15.9$, $p<0.01$. Only the interaction between the effects of Conditions and Trialtype was significant ($F(2,22)=6.8$, $p=0.005$).

The simple effect of Trial type was tested at each level of Conditions, by way of simultaneous test procedures (Betz and Levin, 1982), (MS-error=823.1, df=22, i.e., MS of the interaction Trialtype x Conditions x Subjects). Positive and negative trials did not differ significantly in the control condition, whereas in the grouping and cue condition, larger mean RTs occurred in the negative trials ($p<0.05$). Likewise, simple effects of Conditions were tested at each level of trial type. For positive trials, there were significant differences among the mean RTs of the control, grouping and cue condition ($p<0.05$). For negative trials, there was a significant difference between the means of the control and the cue condition as well as between the control and the grouping condition, but there was no significant difference between the grouping and cue condition.

In short, the above analyses show that grouping decreases the intercept of both positive and negative set-size functions, without affecting the slopes. Also, positive trials benefit more from grouping than negative trials. Cueing a grouped list enhances the beneficial effect, but only for positive trials.

As a further test of the parallel set-size functions, a 3x2 ANOVA was performed on the slopes of individual set-size functions, with factors Conditions (control vs. cue vs. grouping) and Trialtype. In the control condition, linear set-size functions were calculated for each subject, on three individual mean RTs for list lengths 2, 4 and 6, employing the least-squares method. The slopes of the individual functions were typically about 0.40. The individual means correlated typically over 0.95 with these functions, supporting the view that the set-size functions are essentially linear. Individual slopes in the grouping and cue condition were calculated on the means for set size 4 and 6. The ANOVA indicated neither a significant main effect for Conditions ($F(2,22)=1.2$) and for Trial type ($F(1,11)=0.9$), nor a significant interaction ($F(2,22)=0.15$), confirming that the slopes in all conditions are essentially parallel.

Serial Position effects

Figure 2 presents mean RT in positive trials as a function of serial position of the item matching the probe, for each condition, list length and separately for the list structures 2-4 and 4-2. Figure 2 shows that the bow-shaped SP-curves observed in the control condition are drastically reshaped by grouping and that the grouping effect extends over all serial positions. Yet, the bow-shaped form of the SP-curve for four-item sublists is preserved, for list structure 4-2. It is also worth noting that the performance level of the four-item sublist in the grouping condition approaches the level of the four-item control list. The same is true for the two-item sublists from the six-item lists. However, this is not the case with cued lists.

To compare conditions at each serial position, a (6x3) ANOVA was run for six-item lists, separately for list structure 2-4 and 4-2, with factors SP and conditions (control vs. grouping vs. cueing). For list structure 4-2, the main effects of SP and Conditions were both significant (SP: $F(5,55)=14.2$, $p<0.001$; Conditions: $F(2,22)=22.2$, $p<0.001$). The SPxConditions interaction was not significant ($F(10,110)=0.6$). A simultaneous test procedure (Betz and Levin, 1982) showed that, for list structure 4-2, all pairwise comparisons between control, grouping and cueing levels were significant ($p<0.05$) and that the significant effect of SP is mainly due to longer recall latencies at SP 2, SP 3 and SP 4, as compared to the remaining SPs.

To assess effects of conditions separately for each sublist from six-item lists with structure 4-2, an ANOVA was performed on the first and on the second sublist, with factors Conditions (control vs. grouping vs. cueing) and SP. For both sublists, the main effect of Conditions was significant. The effect of SP was only significant in the first (four-item) sublist. The effect of the SPxConditions interaction was non-significant in both analyses. (First sublist: Conditions $F(2,22)=19.2$; SP: $F(3,33)=10.5$; Second sublist: Conditions $F(2,22)=12.3$; $p<0.001$ in all cases). A simultaneous test procedure (Betz & Levin, 1982) between levels of Conditions showed that in the

Figure 2

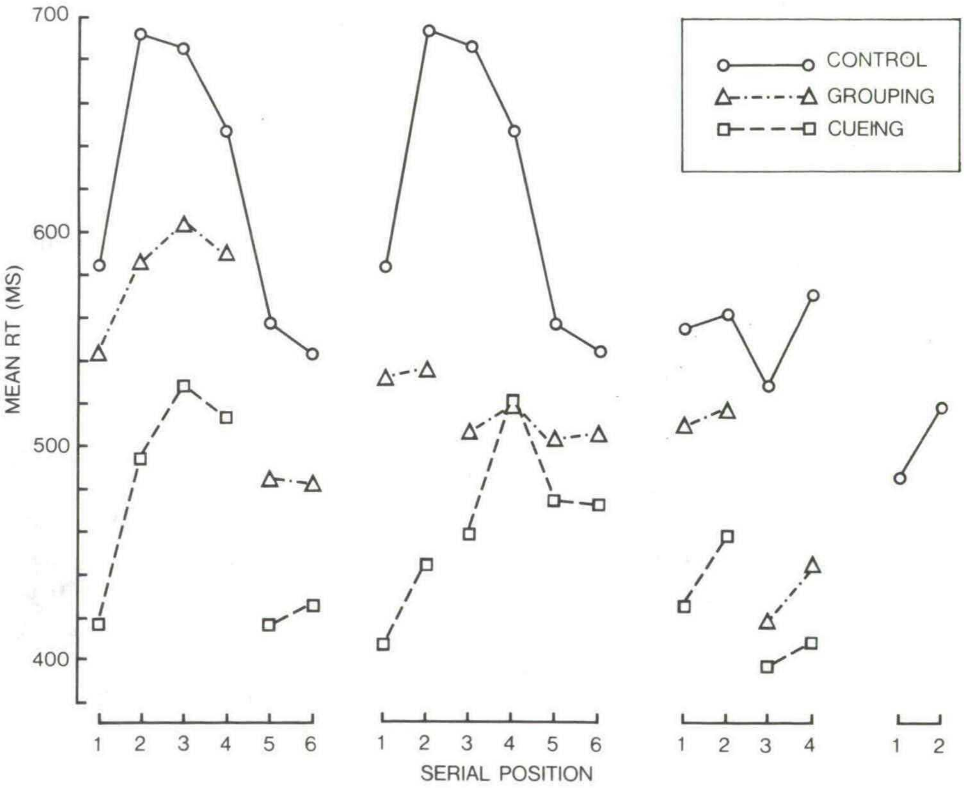

Figure 2: Mean correct reaction time (RT) in positive trials as a function of serial position, in the control condition (circles), the grouping condition (triangles) and the cueing condition (squares). Left panel: six-item lists. Middle panel: four-item lists. Right panel: two-item control list.

first sublist the major effect of Conditions was due to the difference between the control and the cueing condition ($p<0.0001$) and between the grouping and cueing condition ($p=0.01$). Moderate significance was found between the grouping and the control condition ($p=0.03$). Figure 2 shows that this difference is mainly due to SP 2 through 4. To evaluate the relative small grouping effect at SP 1, an F-test revealed no significant decrease of RT relative to the control value ($F(1,11)=1.6$).

In the second (two-item) sublist, a simultaneous test between levels of Conditions indicated significant differences between the control and the grouping condition ($p=0.04$) and between the control and the cueing condition ($p<0.001$). The difference between grouping and cueing was not significant.

For list structure 2-4, a (6x3) ANOVA with factors SP and Conditions showed that both main effects as well as the interaction were significant (SP: $F(5,55)=3.2$, $p=0.01$; Conditions: $F(2,22)=28.4$, $p<0.001$; SPxConditions: $F(10,110)=5.2$, $p<0.001$). For list structure 2-4, pairwise comparisons between control, grouping and cueing levels (Betz and Levin, 1982) showed that RT in the grouping and the cueing condition did not significantly differ, but each of these conditions was significantly shorter than the control level ($p<0.05$). A further analysis of the simple main effects of the significant SPxConditions interaction revealed that at SP 2, and SP 3, there was a significant difference between the control and the grouping condition, as well as between the control and cueing condition. At SP 1 and SP 2, there was a significant difference between the control and the cueing condition. The remaining comparisons at individual SPs were not significant (overall alpha=0.10, MS-error=4269, df=110; SP x Conditions x subjects). A similar comparison (for list structure 2-4) between the levels of recall latency between serial positions within each condition showed only significant differences between SPs in the control condition.

Similar analyses were performed for four-item lists. A 4x3 ANOVA was run, with factors SP and conditions (control vs. grouping vs. cueing). Both main effects were significant (SP: $F(3,33)=7.5$, $p<0.001$; Conditions: $F(2,22)=24.5$, $p<0.001$). The SPxConditions interaction reached marginal significance ($F(6,66)=2.0$, $p=0.08$). A simultaneous test procedure showed significant differences between all pairwise comparisons between the control, grouping and cueing conditions ($p<0.05$). A further analysis of the simple main effects of the SPxConditions interaction at each SP showed a significant difference between the control and the cueing condition at all SPs. The difference between control and grouping was only significant at SP 3 and at SP 4 (overall alpha=0.10, MS-error=3218, df=66; SP x Conditions x subjects). The remaining differences between conditions were not significant. Similarly, the levels of recall latency were compared between serial positions within each condition. Significant differences between SPs were only found in the grouping condition.

Comparisons among sublists

Comparisons among the mean RTs of sublists in the grouping condition and the two-item control lists were performed in a set of ANOVAs with sublist as a single factor. For the two sublists from six-item lists with list structure 2-4, there was no significant difference among the means of the two-item list, sublist 1-2 and sublist 3-6. ($F(2,22)=0.9$). In contrast, the ANOVA on list structure 4-2 showed a significant main effect ($F(2,22)=7.8$, $p<0.01$). A simultaneous test on the levels of this factor showed a significant difference between the two-item list and sublist 1-4 and between sublist 1-4 and sublist 5-6. The difference between sublist 5-6 and the two-item list was not significant.

A similar ANOVA on the four-item sublists from six-item lists in the grouping condition and the four-item control list showed that the four-item control differed significantly from sublist 1-4, but not from sublist 3-6. The difference between sublists 1-4 and sublist 3-6 was also significant ($F(2,22)=4.5$, $p=0.02$).

The two-item sublists from the four-item lists in the grouping condition were compared to the two-item control list in an ANOVA with sublists as single factor ($F(2,22)=16.3$, $p<0.001$). There was a significant difference between the two-item control list and sublist 3-4, as well as between sublists 1-2 and 3-4. There was no significance bewteen the levels of the control list and sublist 1-2.

Similar comparisons among sublists in the cueing condition were performed. Four-item sublists from six-letter lists (i.e. sublist 1-4 and 3-6) were compared to the four-item control list in a 3x4 ANOVA with Sublists and SP as factors. Both main effects were significant (Sublists: $F(2,22)=11.9$; SP: $F(3,33)=5.4$) as well as the SPxSublist interaction ($F(6,66)=3.6$; $p<0.01$ in all cases). There was a significant difference between the four-item control and each of the cued sublists.

Two-item sublists from cued six-letter lists (sublist 1-2 and 5-6) were compared to the two-item control list in a 3x2 ANOVA with factors Sublists and SP. Only the main effect of Sublists was significant ($F(2,22)=11.6$, $p<0.001$), which was due to significant differences between the control lists and each of the cued sublists. A similar ANOVA on the cued two-item sublists from four-letter lists and the two-item control lists indicated significant main effects of Sublists ($F(2,22)=10.7$, $p<0.001$) and SP ($F(1,11)=8.2$, $p=0.02$). The two-item control differed significantly from each of the cued sublists.

Discussion

Although the linear set-size functions in the control condition agree with previous studies and with the main predictions of serial search, both the exhaustive and self-terminating versions of the serial model are clearly at odds with the present results on grouping. The exhaustive model predicts no grouping effect for negative probes, while there are substantial benefits for both trialtypes. This result argues also against self-terminating search which predicts no grouping effects at all.

The exhaustive serial model

The results on grouping also contradict some quantitative predictions derived from the exhaustive serial-search model (see Appendix). The predicted grouping effects for positive trials were 30 msec and 40 msec for four- and six-letter lists, respectively, assuming a search rate of 30 msec/item, which corresponds to the observed rate in the present control condition. However, the observed grouping effects were 81 msec and 81 msec, respectively. (See table 2.) One might object that the observed grouping advantage may partly reflect effects of prolonged practice. However, even if the surplus advantage of 41 msec for six-letter lists would be entirely due to practice, one would also expect a similar practice effect for negative probes, and, furthermore, the predicted advantage of precueing should in principle increase from 80 to 121 msec, for positive as well as for negative probes. In contrast, the observed effect was 63 msec for negative probes (grouping), and the cueing effect was 141 msec and 98 msec, for positive and negative probes, respectively. Hence, even with a substantial effect of practice, or with an additional encoding advantage due to the temporal list structure, the present results diverge in both directions from the predicted values.

The exhaustive serial-search model predicts that the cueing effect should be twice as large as the grouping effect (i.e., 60 msec and 80 msec, respectively, see Appendix). However, the observed effects were 131 msec and 141 msec. Thus, the cueing effects in positive trials are neither twice the observed, nor twice the predicted grouping effects.

The cueing effects for negative trials were 91 msec and 98 ms for four- and six-letter lists, respectively, whereas the predicted effects were 60 and 90 msec, respectively, assuming no bias for either sublist (see Appendix). Hence, only one out of eight predictions based on exhaustive serial search was confirmed, namely for negative trials in six-letter lists.

The self-terminating serial model

A serial self-terminating model predicts no effects of grouping, in the sense that grouping does not affect the point at which memory search is terminated (see table 1). However, it does not exclude different encoding effects for positive and negative probes. As mentioned in the introduction, inserting a pause could improve the encoding of list items at the sublist boundary which may facilitate the comparison of these items with the probe. As a result, grouping could speed up search rate. Hence, some positive effect of grouping does not conflict with the self-terminating model, provided that the advantage is also observed for negative probes (see table 1), since the self-terminating model includes the additional assumption that the search set includes negative items, in order to explain equal search rates for positive and negative probes. Therefore, the negative elements of the search set will have a low priority of search order relative to positive elements. This explains the somewhat elevated RTs for negative responses. Hence, if grouping speeds up the comparison process for some or all of the positive items, negative items will have the greater benefit due to their low search priority. Thus, an encoding advantage due to grouping should be more pronounced for negative probes, which is clearly not the case.

In addition, the grouping advantage should be most clearly observed for matching items at the group boundary. In other words, grouping should reshape the serial-position curve, which relates RT to the position of the matching item in the memory list. This latter prediction follows from the reduced search rate for the matching boundary item, due to enhanced encoding. If the probe matches a non-boundary item, the boundary item may not always be included in the search, due to a low search priority. Hence, the advantage is not always refected in RT. Since the encoding advantage due to grouping would mainly occur at the boundary positions, the effect is not expected to be large. For instance, assuming a 50 % reduction of the comparison rate for the better encoded items, the net advantage would be the time to process one item, that is about 30 msec in the present experiment. Thus, the present results do not indicate that grouping causes substantial effects of encoding.

Conclusions on serial-search models

Both serial models expect effects of cueing on RT which should be larger when the probe matches an item contained in the smaller subset. Yet, the 4-2 condition shows a general effect of cueing that does not depend on subset size, while in the 2-4 condition the effect of set size was fully restricted to the smaller subset (see figure 2).

In conclusion, the predictions of both serial models on effects of grouping and cueing are not confirmed. Furthermore, the strong effect of serial position (SP) poses an additional problem for exhaustive serial search. It requires the strong additional assumption that the duration of making a match depends on the SP of the matching item (e.g., Townsend, 1974; Taylor,1976). On the other hand, a self-terminating model can handle SP effects, provided a certain search order, but this model cannot easily explain the virtual absence of SP effects in the 2-4 condition.

Further remarks

The bow-shaped SP effects in the control condition replicate the results of previous studies (e.g., Corballis, Kirby & Miller, 1972). On the other hand, the general decrease of latency in the grouping condition conflicts with Burrows & Okada's (1974) finding that insertion of a pause during list presentation caused a small delay (about 28 msec), which was constant over set size and, according to these authors, acted as an additional item in a serial exhaustive search.

The equal slopes of the set-size functions across conditions do not confirm the finding of Burrows & Okada (1975), who reported a negative effect of cueing, that is, larger slopes when a temporally segmented list was cued. An essential difference with the present cueing method can account for these divergent results. In the Burrows & Okada study, some of the probes were "internal negatives", that is, probes that matched an item from the uncued part of the list and therefore required a negative response. In the present experiment, a match never occurred in the uncued sublist; thus a less complex discrimination was required.

Alternative recognition models

Both serial models are challenged by the present results and, therefore, it is worthwhile to consider parallel models of memory search. In this type of model, all memorized items are compared simultaneously with the probe. A parallel model explains the increasing set-size functions by a decrease of available processing capacity for individual items, as more items are searched. Processing capacity for memory search is assumed to be limited. Multiple comparisons between the memorized items and the probe are carried out, either until a match occurs (self-terminating search) or until the slowest comparison proces is completed (exhaustive search). The SP effects argue against an exhaustive version of the parallel model, whereas Taylor (1976) has shown that in a self-terminating parallel model the slope of the set-size function for negative trials should be substantially steeper than for positive trials, assuming an exponential distribution for elementary processing times (see also McNicol & Stewart, 1980). Therefore, a self-terminating parallel model should be rejected on account of the finding that in the control condition the set-size functions for positive and negative trials have equal slopes. In conclusion, the present results in the control condition cast serious doubts on both types of parallel models.

In a third class of recognition models, termed direct access models, there is no search at all through the memorized list. Instead, the memory representation of the probe is accessed directly, followed by retrieval of contextual attributes, which are evaluated in terms of familiarity and recency, in order to decide whether or not it occurred in the list. Thus, in this view, recognition requires a search for contextual attributes of the memory represrentation of the probe (cf. Anderson & Bower, 1972; Atkinson & Juola, 1973).

These notions can be expressed in terms of signal-detection theory: On the average, positive probes will have a greater strength of contextual atttributes than negative probes.

Table 3

Signal-detection analysis of mean RTs
in six-item control lists.

	Negative probes	Positive probes	
		interior SPs	extreme SPs
Correct response	CORRECT REJECTIONS	HITS	
	624	674	562
Incorrect response	FALSE ALARMS	FALSE NEGATIVES	
	686 (3)	700 (8.8)	620 (5)

NOTE: Reaction time in msec. Error percentages in parentheses. Interior SPs: serial positions 2, 3 and 4. Extreme SPs: serial positions 1, 5 and 6.

The speed of the binary decision is assumed to increase as the trace strength diverges in either direction from an adjustable strength criterion. In a direct-access model, limited capacity is distributed among items as they are presented. In particular, capacity will be allocated to a newly presented item at the expense of earlier presented items. This reallocation of capacity has two consequences. First, increasing set size decreases the average trace strengths of positive items and, consequently, the subject will lower the strength criterion. Thus, recognition latency for both positive and negative probes will increase as a function of set size. Second, strong recency effects are expected and possibly also primacy effects, due to rehearsal. Thus, trace strength varies across SPs, due to acquisition or storage factors. This explains the bow-shaped SP curves (see Baddeley & Ecob, 1973; Sternberg, 1975). Thus, the direct-access model accounts well for the results in the control condition.

Further support for the explanation of the SP-effects in terms of differential contextual strengths, within the context of a direct-access model, stems from a signal-detection analysis of mean RTs for correct and incorrect responses. The SP-curve for 6-item control lists shows that mean RT at the interior positions (SP 2, 3 and 4) are substantially larger than the level observed for the extreme serial positions (SP 1, 5 and 6), suggesting that signal strength for the former positions are less discriminable from the strengths of negative probes. Table 3 shows mean RTs for correct and incorrect responses and error rates in the control condition, separately for the middle SPs, the extreme SPs and for negative probes.

Assuming that reaction time is inversely proportional to the difference in strength with the criterion value, the data in table 3 are easily interpreted by proposing three partially overlapping strength distributions on a strength continuum, one for the negative probes, one for the low-strength positive probes (matching at SP 2, 3 or 4) and one for the high-strength positive probes (matching at SP 1, 5 or 6). The means of these respective distributions represent increasing levels of strength. Since error rates for positive probes are higher than for negative probes, the criterion value is somewhat conservative, that is, cutting off a larger portion of the signal distribution (false negatives) than from the noise distribution (false alarms). Both types of errors result from instances in which item strength is close to the criterion value. Hence, mean RT for errors is relatively large (i.e., 700 msec for false negatives and 686 msec for false alarms). In contrast, correct responses originate from strength values, most of which differ substantially from the criterion. Thus, correct responses are faster (674 msec and 624 msec for hits and correct rejections, respectively). Mean RT for hits is larger than for correct rejections because the -- conservative -- criterion is closer to the mean of the positive-probe distribution than to the negative distribution. In line with the view that the distribution for extreme SPs has the greater mean strength, the error rate for interior SPs is greater (8.8 %) than for extreme SPs (5 %) and mean RT for hits is also larger (674 msec vs. 562 msec).

The beneficial effect of grouping across all serial positions can be explained in a direct-access model by assuming that contextual attributes are set up for each sublist. Consequently, these attributes are stronger when shared by fewer items and the contextual-strength distributions of positive probes shift away from the distributions of negative probes. Hence, $\underline{d}'$ increases and the average strength of positive as well as of negative probes differs increasingly from the criterion, causing faster recognition for both types of probe. This view is confirmed (see figure 2) by the fact that the average performance levels of the four-item sublists approach the level of the four-item control condition (although a residual difference remains between list structures 2-4 and 4-2, due to the recency advantage for the former structure). Similarly, performance in the 2-item sublist (from the six-item list) approaches the level of the two-item control.

The effects of cueing of a grouped list can also be explained by direct-access. Evidently, the cueing advantage is not due to shifts in the criterion, but reflect an enhanced sensitivity ($\underline{d}'$), since recall accuracy is not affected. Rather, it appears that cueing preactivates the contextual cues of the relevant sublist, thus facilitating the search for attributes of the positive probe. This interpretation is supported by the fact that, with list structure 4-2, the shape of the SP-curve of the four-letter sublist is preserved with cueing, as compared to the grouping condition. In other words, search preactivation appears to facilitate search for contextual attributes, providing a general benefit to all items of the cued sublist. Yet, preactivation apparently does not affect the differences between serial positions as to the ease of deciding whether or not it belongs to the cued sublist. Hence, the shape of the SP-curves remains unaffected, especially with list structure 4-2. These findings provide an interesting correspondence with precueing effects in recall of a single item in response to a positional probe (Hendrikx, 1984 b). In these studies it was concluded that precueing preactivates a retrieval pathway rather than providing additional retrieval cues. This view on precueing seems to be also appropriate for item recognition. In addition, it accomodates the failure to find statistical evidence that precueing did not significantly reduce RT for negative probes. Evidently, search and evaluation of weak cues of a negative probe cannot be facilitated by preactivation of sublist-cues which are irrelevant to that probe.

The grouping advantage observed in six-item lists bears resemblance to probed recall, in which grouping mainly affects the items at the boundary between sublists (Hendrikx, 1984 a; b), by providing additional retrieval cues. The present results also show the most pronounced effects at the sublist boundaries. Yet, the grouping effect in the present recognition study appears to extend also to extreme serial positions, in particular to the most recent items. Prolonged practice is the most parsimonous explanation for this residual advantage in the grouping condition, although an alternative tentative explanation is possible: The relative advantage at the extreme SPs with grouping, as compared to the control, could be due to a <u>dis</u>advantage for these items in the control condition. This disadvantage does exist in the recognition task but it is absent in probed recall: An item-recognition probe does not indicate a direct retrieval pathway via a primacy cue or recency cues, whereas a positional probe does. As a consequence, recognition performance in the control condition is at a relative disadvantage, since the item representation itself is used as a retrieval cue, instead of the unique positional cue. Hence, recognition performance at extreme SPs also benefit from grouping, while recall is unaffected. An alternative interpretation of the grouping advantage at extreme SPs in terms of better encoding of the items seems to be excluded by the absence of such an advantage in probed recall (Hendrikx, 1984 a)

In conclusion, it appears that the principles on retrieval in immediate recall, as formulated in the positional cueing theory of short-term retention (Sanders, 1975), also provide a valid desciption of retrieval processes within a direct-access model of short-term item recognition. In probed recall the positional primacy and recency cues guide direct access to particular items, such as the first item or the few last items. In recognition, positional cues are retrieved via direct access to an item probe and subsequently facilitate the decisional process as to whether or not the probe occurred in the memory list.

Appendix

The grouping effect

Quantitative predictions about the size of the grouping effect, for positive probes only, can be deduced from an exhaustive serial-search model, as follows. With grouping, a list of n items is divided into a larger and a smaller sublist. Search is terminated after completion of the sublist in which the matching item is encountered.

-Let $\underline{T}$ denote the expected average search time.
-Let r denote the search time per item (say, 30 msec).
-Let n denote list length (set size).
-Let p denote the proportion of items within the larger sublist; $0.5 < p < 1$.
-Let q denote the proportion of items within the smaller sublist; $q = 1 - p$.

Assume that p and q also define the probability that, respectively, the larger or the smaller sublist is searched first. That is, there is no bias for either sublist, apart from its relative size. (Alternatively, this assumption on a bias due to relative size can be omitted, so that p=0.5 for any type of grouping. However, we will first derive predictions based on the "relative-size assumption".)

For ungrouped lists, all memorized items will be searched; therefore, $\underline{T} = nr$. On the other hand, for grouped lists a formula for $\underline{T}$ will be derived for two separate cases:

First, consider the case in which the probe matches an item in the larger sublist. Let $\underline{T}'$ denote conditional search time:

-If the larger sublist is searched first, then $\underline{T}' = npr$
-If the smaller sublist is searched first, then $\underline{T}' = nr$

Hence, the expected average search time is the weighted sum of the conditional search times:

[NOTE: p-SQUARED IS NOTATED HERE AS p'']

$$\underline{T} = p(npr) + q(nr)$$

Thus:

$$\left.\begin{array}{l} \underline{T} = (p'' + q)nr \\ \\ q = 1 - p \end{array}\right\} \longrightarrow \underline{T} = (p'' - p + 1)nr$$

Second, consider the case in which the probe matches an item in the smaller sublist:

-If the smaller sublist is searched first, then $\underline{T}'= qnr$

-If the larger sublist is searched first, then $\underline{T}'= nr$

Hence, the weighted average is:

$$\left.\begin{array}{l} \underline{T}= p(nr) + q(nqr) \\ \underline{T}= (q''+ p)nr \\ \\ q= 1-p \end{array}\right\} \longrightarrow \underline{T}= (p''-p+1)nr$$

This formula is identical to the formula obtained in the case the probe matched in the larger sublist. Thus, the average expected search time $\underline{T}$ does not depend on which of the sublists contains the probe-matching item. Rather, $\underline{T}$ depends only on p, that is, on the relative size of the sublists.

The grouping effect $\underline{G}$ can be expressed as the difference with the ungrouped condition, in which $\underline{T}= nr$.

$$\underline{G}= nr-(p''-p+1)nr= (p-p'')nr$$

Thus, the search advantage caused by grouping is (p-p'')r. This expression shows that the maximal search advantage is obtained when the sublists are of equal size, that is, when $\underline{p}$=0.5.

Applying the above derived expressions to a six-item list, divided into a four-item and a two-item sublist, we have: $\underline{n}$= 6 and $\underline{p}$= 2/3 and $\underline{r}$= 30 ms.

Thus: $\underline{T}= [(2/3)x(2/3) +1 -2/3] \times [6x30]$

$\underline{T}= [7/9] \times [6x30]$

In contrast, for an ungrouped list $\underline{T}= [6x30]$

The grouping effect, obtained by subtraction, is:

2/9[6x30]= 40 ms,

This is confirmed when $\underline{G}$ is obtained directly by using the expression $\underline{G}$= (p-p'')nr

$$\underline{G}= [2/3-4/9] \times [6x30]= 2/9[6x30]= 40 \text{ ms}$$

If the "relative-size assumption" is omitted, $p = 0.5$ irrespective of the list structure and, thus, $\underline{T} = (3/4)x(6x30) = 135$ and consequently $\underline{G} = 45$ ms. Thus, the prediction on the grouping effect remains virtually unchanged.

Likewise, we can find the grouping effect for a four-letter list, divided into two equal sublists. We have: $\underline{n}=4$ $\underline{p}=1/2$ Hence,

$$\underline{G} = (1/2-1/4)x120 = 30 \text{ ms}$$

The cueing effect

In this section we will derive predictions from the serial exhaustive search model on the effect of cueing one of the sublists from a grouped list. A match with the probe can occur only in the cued sublist. In contrast to the grouping effect, cueing also affects negative trials (i.e., trials in which none of the items matches the probe). To determine the conditional search time $\underline{T}'$, two cases should be distinguished:

- If the probe matches in the larger sublist, $\underline{T}' = pnr$
- If the probe matches in the smaller sublist, $\underline{T}' = (p-1)nr$

The average expected search time $\underline{T}$, is the weighted sum of the conditional search times, assuming an even distribution of the matches across SPs: $\underline{T} = p(pnr) + q(qnr)$

$$\underline{T} = (p'' + q'')nr$$

$$\underline{T} = [p'' + (1-p)'']nr$$

Hence,

$$\underline{T} = (p'' - p + 1)nr - (p - p'')nr$$

We obtain the cueing effect $\underline{C}$, by taking the difference with the control condition (ungrouped and uncued), in which $\underline{T} = nr$

$$\underline{C} = nr - [(p'' - p + 1)nr - (p - p'')nr]$$

$$\underline{C} = nr(1 - p'' + p - 1 + p - p'') = 2(p - p'')nr$$

This expression shows that the cueing effect is positive and twice as large as the grouping effect. As with grouping, the maximal gain occurs with p= 0.5, that is, with equal sublists. Furthermore, C depends on n, which means a greater cueing advantage for longer lists. (This will not be tested in the present experiment.)

Applying these expressions again to a grouped six- or four-item list, we obtain:
For the six-item list, with structure 2-4 or 4-2, in which p=2/3 n=6 and r= 30 ms: C= 2(2/9)x(180)= 80 ms

> If the "relative-size assumption" is omitted, p= 0.5, and thus, C= 90 ms for a six-item list.

for the four item list, with structure 2-2:
C= 2(1/4)(120)= 60 ms.

In summary, the following set-size functions were derived:

- control condition $T = nr$
- grouping condition $T = (p'' - p)nr$
- grouping and cueing $T = (p'' - p + 1)nr - (p - p'')nr$

These expressions imply an increasingly smaller slope and intercept of the set-size functions for the control, grouping and cueing conditions. In other words, the exhaustive serial search model predicts divergent set-size functions.

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CHAPTER 8

COMPATIBILITY OF PRECUEING AND OF S-R MAPPING IN CHOICE REACTIONS

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COMPATIBILITY OF PRECUING AND OF S–R MAPPING IN CHOICE REACTIONS *

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This study investigates information processing elicited by precuing a subset of alternatives in a choice reaction task. The aim was to study the influence of some task variables on the effectiveness of precuing, in order to determine the locus of differential precuing effects, in either central decisional processing or in motor programming. Partial advance information (PAI) was given 300 msec in advance of the action signal and it indicated the subset from which the action signal would be chosen. Thus, precuing reduced the number of alternatives. The resulting decrease of reaction time (RT) was assessed under various levels of S–R compatibility, response specificity and cue compatibility. Cue compatibility refers to the naturalness of the (spatial) relation between the cue signals and the stimulus–response pairs. This study shows that (a) precuing effectiveness is strongly affected by cue compatibility, and (b) cue compatibility should be viewed as a twofold concept: it refers to the naturalness of the relation of the cue signal, either with action signals or with responses.

Experiment 1 compared a naming and a pointing task. Although in both tasks the cue signal was compatible with the cued action signals, the naming task had a lower level of S–R compatibility and also a lower level of compatibility between the cue signal and responses. Precuing was highly effective when *pointing* towards the action signal, but hardly effective when *naming* ordinal positions. Experiments 2–4, using only a pointing task, showed a decrease of the precuing effect with a decrease of either type of cue compatibility, although cue compatibility with *action signals* was the strongest factor. Low S–R compatibility further decreased the size of the precuing effect caused by low compatibility between cue and action signals. Differential precuing effects did not result from differences in response specificity (i.e., the lack of similarity among the cued responses). It is concluded that precuing and both types of cue compatibility affect the stage of response decision, while no evidence was found for effects on motor programming. Implications are discussed for movement precuing studies that rely on differential precuing effects to discover properties of motor programming.

In speeded choice tasks, responses usually become faster and more accurate when a subset of alternatives is cued shortly in advance of the action signal. The action signal is always drawn from the precued subset and therefore, precuing reduces the number of possible signal–response (S–R) alternatives. For instance, in a 6-choice key pressing task, Leonard (1958) found that when three alternatives were precued 300 msec in advance of the action signal, reaction time (RT) was fully reduced to the level of a 3-choice control condition. Thus, processing load was optimally reduced to the level of uncertainty (Hick 1952; Hyman 1953) as defined by the number of precued alternatives. Reaction time (RT) is known to increase as a function of number of alternatives. Hence, common mechanisms of information processing seem to be affected by precuing and number of alternatives.

In principle, precuing may affect any combination of three basic mental operations: (a) perceptual processes leading to signal identification, (b) response decision processes in which a stimulus code is translated into a particular response code (e.g. Theios 1975), and (c) response programming processes which elaborate and translate this response code into a motor program, that is, a structured set of response commands (e.g., Kerr 1978). This view accords with linear stage models (Sternberg 1969; Sanders 1980), in which, subsequent to perceptual processing, a central response decision stage precedes one or more motoric stages, such as 'response programming' (e.g., Spijkers and Walter 1985).

If there is a common mechanism responsible for the effects of precuing as well as number of S–R alternatives, effects of precuing might be ascribed to the stage of response decision, since number of alternatives is known to have a major locus at that stage. Yet, the number of alternatives does probably also affect processing at other stages, perceptual as well as motor (Sanders 1980). More direct support for the response decision hypothesis would consist of interactive effects of precuing and of S–R compatibility. The latter variable refers to the 'naturalness' or 'obviousness' of the relation between action signals and responses (Fitts and Seeger 1953). It is well established that S–R compatibility exclusively affects response decision processes, in that less compatible S–R relations increase the complexity of the translation from signal to response code. Thus, the size of the slope relating RT to number of alternatives is a function of S–R compatibility (e.g., Welford 1968; Teichner and Krebs 1974; Sanders 1980).

One aim of the present study was to investigate whether precuing effects are indeed modulated by S–R compatibility and hence, whether precuing affects *central decisional processes.* This question is also of importance, since recently the precuing technique has become an important tool in the study of the way in which movements are planned and prepared in advance of overt action. Rosenbaum (1980) developed a line of research which investigates the effects on RT of precuing various movement parameters, such as direction and extent. It was reasoned that when precuing causes faster responding, the cued aspects of the movement are programmed in advance, so that the motor program is partially completed before the occurrence of the action signal. Hence, it is assumed that precuing reduces the processing load and structure of *response programming.* Rosenbaum (1980, 1983) reported differential precuing effects, depending on the type of movement parameter that was precued, and concluded that certain aspects of movements can be more easily programmed than others. However, as pointed out by Stelmach and Larish (1981) and Goodman and Kelso (1980), serious doubt can be raised as to whether movement precuing effects can be attributed unambiguously to response programming, since the effects may as well reflect a confounding with preceding non-motoric processes of response decision. Both studies showed that the effectiveness of precuing depends on S–R compatibility, since differential effects of precuing were only obtained with *in*compatible signal–response relations.

Next to S–R compatibility, however, there is another type of compatibility that should also be considered. This factor will be termed *cue compatibility.* It is concerned with the relation between the *precuing signal* and the *cued subset of S–R alternatives.* For example, with a direct spatial mapping of action signals and responses in a horizontal array, compatible precuing of – say – the two rightmost alternatives would consist of cue lights at the two rightmost locations, whereas instances of less cue-compatible precuing would consist of the two leftmost cuelights, or, alternatively, of presenting the word 'right' instead of cue lights. Hence, the effect of precuing might be a function of cue compatibility, in that more cue-compatible cue signals may facilitate response decision, response programming, or both.

Differential effects of movement precuing have been obtained by Miller (1982), using two orthogonal parameters (i.e., hand and finger) that specified four distinct finger movements. Any two out of four possible responses were precued. At short intervals (i.e., less than 1 sec), precuing was beneficial when the precued responses were on the same hand, whereas precuing fingers from different hands was not beneficial. Miller (1982) concluded that precuing differentially facilitates motor processes because programming is hierarchical, that is, in programming the response, movement parameters related to which hand to use should always be specified before other aspects of the movement. Apparently, this requirement impairs advance programming of responses from different hands. Yet, this conclusion has been challenged by Reeve and Proctor (1984), who showed that this 'same-hand advantage' depended on particular spatial properties of the precuing signals and not on an ability to program same-hand responses more rapidly: a similar precuing advantage could be obtained for *different*-hand responses by changing the signal–response mapping. Reeve and Proctor therefore concluded that the differential precuing effects did not reflect motor programming but should rather be explained as differential facilitation of non-motor, decisional processes which depend on the spatial characteristics of the precuing signals, that is, on cue compatibility.

The foregoing suggests that two factors are likely to be involved in the effectiveness of precuing: cue compatibility and S–R compatibility. The present study attempts to clarify the role of these compatibility factors. In addition, it addresses the related issue as to the possible location of the precuing effects in a central response decision stage, in response programming, or in both.

Experiments 1 and 2 manipulated S–R compatibility, while the relation between precuing signals and action signals was held constant by using the same spatial array of cue and action signals. S–R compatibility was varied in two distinct ways: experiment 1 employed different response modes, namely, a manual *pointing* task, which entailed a spatially compatible mapping of signals onto response keys, and a vocal *naming* task, in which signal positions were named. This last task has been shown to be much less compatible (cf. Brainard et al. 1962). In experiment 2, S–R compatibility was varied in the same pointing task, by changing the spatial translations between action signals and response keys.

Experiments 1 and 2 showed large variations in the size of the precuing advantage that cannot have been merely caused by S–R compatibility. In experiment 1, precuing fully reduced RT in the compatible task (pointing), whereas only slight effects were observed in the incompatible task (naming). In experiment 2 (pointing), precuing fully reduced RT irrespective of S–R compatibility. It was proposed that the change of response mode from pointing to naming in experiment 1 might have decreased both S–R compatibility and cue compatibility, and that only the latter factor could be responsible for the differential precuing effect. Experiments 3 and 4 further investigated the influence of cue compatibility by manipulating the spatial translations between cue signals, action signals and responses.

Experiment 1

S–R compatibility was varied by using a pointing task and a naming task. The tasks differed in response repertoire, but employed the same cue signals and action signals. Hence, differential precuing effects of a perceptual nature were excluded. Experiment 1 investigated the effect of a reduction from 6 to 3 S–R alternatives, from 6 to 2 alternatives and from 4 to 2 alternatives.

The basic design of experiment 1 consisted of a triplet of precuing (PAI) conditions: a total control condition, a subset control condition and a cue condition (see table 1). These conditions were presented in separate blocks. PAI was presented only in the cue condition. The two control conditions set upper and lower limits to performance in the cue condition. This triplet was replicated three times. Two replications involved a 6-choice task, in which either two or three alternatives were cued. A third replication involved a 4-choice task, in which two alternatives were cued.

Method

Experimental tasks

Both the pointing task and the naming task required choice reactions to the same visual signals, presented in a horizontal array and mapped one-to-one onto the responses. The signal display consisted of two horizontal rows of six lights. The top row contained cue lights that were used to cue the forthcoming action signal. The bottom

Table 1
Precuing (PAI) conditions in experiment 1.

PAI conditions	Triplet		
	1	2	3
Total control	6-choice	6-choice	4-choice
Cue condition	6–2	6–3	4–2
Subset control	2-choice	3-choice	2-choice

row contained the action signal and consisted of response keys with built-in pea-lights. The start of each trial was signalled by a tone, followed by a cue signal, consisting of two or three adjacent cue lights, that appeared for 300 msec in the top row. The action signal was one of the six lights in the bottom row and it appeared at the same time that the cue signal was removed. The position of the action signal in the array always coincided with one of the activated cue lights. In the total control and the subset control conditions, the entire array of cue lights was activated, and hence the cue signal was uninformative and only served as a temporal warning signal.

In the *pointing* task, subjects pressed the response key coinciding with the action signal with the right index finger. At trial onset the subject's right index finger was positioned on a release key, located below the centre of the array of response keys. Subjects were instructed to release this key only after deciding on the proper response key. RT was measured in msec from presentation of the action signal until departure from the release key. The interval from release until pressing the appropriate response key was defined as movement time (MT).

In the *naming* task subjects pronounced the numeral 'one', 'two', etc. associated with the spatial position of the action signal from left to right. A microphone in front of the subject recorded the responses through activating a relay at a certain sound pressure. The sensitivity was adjusted to the voice characteristics of each individual subject. Activation of the relay terminated the RT interval.

Subjects were encouraged to closely attend to the cue lights and to use that information in order to respond as quickly as possible when the action signal was presented.

Precuing conditions

In the *total control conditions* the action signal alternative for an individual trial was randomly chosen from the total set, which consisted of either four or six alternatives. *All* cue lights were jointly lit (i.e., 4 or 6) and, hence, there was no partial advance information. These total control conditions were respectively named '*4-choice*' and '*6-choice*'.

In the *cue conditions,* PAI was presented by cuing a random subset of spatially adjacent locations from the total array. Thus, two or three cue lights were jointly presented. The action signal was randomly chosen from this cued subset. For the 6-choice task the cued subset contained either two or three alternatives. These cue conditions are respectively named '*6–2*' and '*6–3*', the digits respectively referring to the number of relevant alternatives before and after cue presentation. In condition '6–2', subsets occupied locations (1,2), or (3,4), or (5,6). In condition '6–3' these locations were (1,2,3), or (4,5,6). For the 4-choice task the cued subsets always contained two alternatives. This was condition '4–2', with subsets located at (1,2) or (3,4).

In the *subset control conditions*, fixed subsets of adjacent signals were tested in isolation. In a block of trials, subset location always corresponded to one of the subsets in a cue condition. All cue lights from the subset were jointly presented and were thus uninformative. Subjects knew in advance which subset of three or two positions were used. In the 6-choice task, the fixed subset contained either two or three adjacent signal positions (i.e., '*2-choice control (6)*' and '*3-choice control (6)*', respectively. In the 4-choice task, fixed subsets of two alternatives were tested (i.e., '*2-choice control (4)*').

In summary, both the pointing and the naming task had eight conditions: two total control conditions (4-choice and 6-choice), three cue conditions ('4–2', '6–2' and '6–3'), and three subset control conditions ['2-choice (4)', '2-choice (6)' and '3-choice (6)'].

Apparatus and display

The subject was seated in a dimly lit sound-attenuated room, at a sloping desk on which an array was mounted of two horizontal rows of six lights. Form and luminance of these lights were identical (diameter 12 mm; 80 cd/m^2). The centers of adjacent lights were 25 mm apart. The release key was located 15 cm below the bottom row of the array. The subject wore headphones through which a warning signal (1000 Hz, 40 dB SPL) was presented for 500 msec at the start of each trial. After a 200-msec interval, the cue signal was presented for 300 msec, followed by the action signal which lasted for 1 sec. After a subsequent interval of 2.7 sec, the warning signal of the next trial occurred. Thus, every 4.7 sec there was a new trial. Signal presentation was controlled by the PSARP equipment (Van Doorne and Sanders 1968).

In the 6-choice tasks, the entire 2×6 array of lights was employed. In the 4-choice tasks, a smaller 2×4 array was employed by covering the two extreme positions of the 2×6 array with cardboard.

In the subset control conditions, only a fixed section of the array was employed at a time. In condition '3-choice (6)', one block of trials was devoted to the right half of the 2×6 array and another block to the left half. Condition '2-choice (6)' employed either the right, middle or left section of the 2×6 array in separate trialblocks. Similarly, condition '2-choice (4)' employed the right or left section of the 2×4 array.

Procedure

Each precuing condition was run in blocks of trials containing 10 trials for each possible position of the action signal. For example, the total control conditions were run in blocks of 60 or 40 trials, respectively, for the 6- and 4-choice tasks. Signal positions were randomized within blocks.

In the cue conditions, the different locations of the cue signal were equiprobable and pseudo-randomly varied. The action signal appeared with equal frequencies and pseudo-randomly in the positions within the subset indicated by the cue signal.

Within each of the three subset control conditions, the different sections of the array were tested in sub-blocks of trials. The order of testing was either from left to right or vice versa. Before each sub-block, the subject was informed about the relevant section of the array.

Blocks were separated by 1-min breaks in which the subject was informed about the condition of the next block and the significance of the cue lights. Each block was preceded by three practice trials. Before the first session the subject was given a practice session for all 8 conditions.

In the naming task, the vocal responses were continuously monitored in order to discard errors of commission and improperly pronounced responses, such as hesitations. Possible effects of premature responses were avoided by excluding from analysis correct RTs less than 70 msec. Such exclusions were incidental. In the pointing task, trials with extremely large (> 310 msec) movement times (MT) were also excluded, as inspection of individual MT distributions suggested that in these trials the response decision had not been completed at the time of response initiation. By analogy, naming responses reflecting any hesitation in pronouncing the correct numeral were judged as premature and were also discarded. As a consequence, 93% of the pointing data were analyzed. Of the naming data 87% were analyzed (also excluding errors of commission, as these were hard to distinguish from hesitations).

Design and subjects

The pointing and naming tasks were run with separate groups of 8 subjects. For each group, an 8 × 8 balanced Latin Square defined for each subject a specific order in which the eight experimental conditions were run. The Latin Square was replicated four times within subjects. In one session all eight conditions were tested once. Each subject participated in four 30-min sessions, separated by 30-min breaks. In the subset control conditions of the second and fourth session, the various sections of the array were tested in reversed order.

Sixteen male and female students from Utrecht University, ages between 17 and 31, participated in the experiment. All subjects were right-handed. They were paid a fixed sum for participation.

Results

Fig. 1 presents mean RTs of correct responses for each condition of the naming task (left panel) and the pointing task (right panel). Data were collapsed over S–R alternatives and means are averaged over 8 subjects. For the total control and subset control conditions, mean RTs are plotted as a function of number of S–R alternatives, while the results of the cue conditions are separately depicted to assess the effectiveness of precuing relative to the levels of total and subset control.

Fig. 1 shows that the effect of precuing strongly differs between the pointing and naming task. For pointing (right panel), mean RT in all cue conditions (i.e., conditions '6–2', '6–3' and '4–2') closely approaches the level of the corresponding subset control condition. In contrast, for naming (left panel), all cue conditions show only a moderate reduction relative to the total control conditions. Three ANOVAs were performed on individual mean RTs, one for each of the three cue conditions and their corresponding subset and total controls. The factors were Response mode (pointing vs naming) and Precuing conditions (total control vs subset control vs cue condition). The results of the ANOVAs are summarized in table 2 and reveal in all cases significant main effects of Response mode and of Precuing and a significant Precuing × Response mode interaction.

For each Response mode, mean RTs within each triplet of Precuing conditions were compared by means of simultaneous test procedures (Betz and Levin 1982). (Error term was the *MS* of the factor Precuing × Subjects within groups, see table 2; $p = 0.05$.) In the pointing task, responses in the cue conditions were always significantly faster than in the total control conditions. In contrast, in the naming task, the cue conditions were significantly slower than the subset controls and did not differ significantly from their

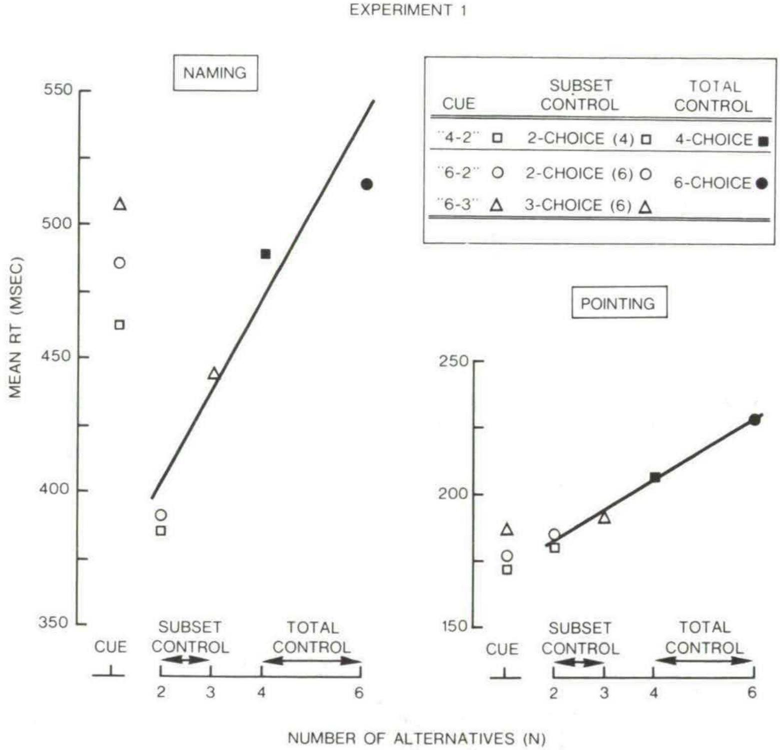


Fig. 1. Mean reaction time (RT) of correct responses in experiment 1, in the naming task (left panel) and pointing task (right panel). RT is plotted as a function of number of alternatives, except for the cue condition, which logically cannot be located on that dimension. The linear functions represent linear regressions calculated on individual means.

Table 2
Analyses of variance on mean RTs in experiment 1.

(2×3) ANOVAs on triplets of precuing conditions						
Source	2 vs 6 alternatives		3 vs 6 alternatives		2 vs 4 alternatives	
	df	*F*	*df*	*F*	*df*	*F*
Response mode (A)	1,14	217.5 [a]	1,14	221.4 [a]	1,14	208.0 [a]
Precuing (B)	2,28	147.8 [a]	2,28	70.8 [a]	2,28	62.0 [a]
Interaction (A×B)	2,28	63.2 [a]	2,28	31.1 [a]	2,28	32.8 [a]
B×subjects within gr.	$df = 28$; $MS = 191.3$		$MS = 162.8$		$MS = 269.8$	

[a] $p < 0.001$.

respective total control conditions, except for condition '6–2' which was faster than its 6-choice control.

Errors

In the pointing task, the rate of errors of commission was low in all conditions and averaged 1.8%, whereas it averaged 13% across the naming conditions (including the responses that were judged as being premature), with a low rate for the subset controls (4%) and high rates for the total control and the cue conditions (typically 17%). Across conditions, error rates were positively related to correct mean RTs, so confounding effects of speed–accuracy trade-off can be discounted.

Movement times

In the pointing task, mean movement times (MT) averaged 181 msec across conditions and differed less than 10 msec among conditions in either direction. Mean MT was positively related to mean RT across conditions, indicating that effects on mean RT did not result from RT–MT trade-off.

Discussion experiment 1

Only the pointing task replicated Leonard's (1958) finding that precuing fully reduces RT to the level of the subset control condition. In the naming task precuing is only partially effective and seems to depend on the *proportion* of the number of cued alternatives relative to the initial number. In the pointing task, it appears that the *number* of precued alternatives is the sole determinant of mean RT.

The interaction between the effects of response mode and number of alternatives (i.e., total vs subset control, see solid lines in fig. 1), confirms the notion that S–R compatibility is an underlying variable between the pointing and the naming task. Naming responses to lights are generally considered as less compatible than pointing responses (Brainard et al. 1962; Broadbent and Gregory 1965). Consequently, the observed difference in precuing effectiveness across response mode may reflect an interaction between S–R compatibility and precuing. Within a linear stage model of reaction time (cf. Sternberg 1969; Sanders 1980), this interaction suggests that precuing affects the response decision stage. The extent of the interaction excludes the possibility that a substantial part of the effect of precuing can be attributed to facilitation of *perceptual* processing stages, which are, of course assumed to be independent of response mode.

Yet, the view that precuing affects response decision processes needs further testing, since S–R compatibility is not the only dimensions on which the pointing and the naming task differ. Two other dimensions can be distinguished. First, the tasks differ also in cue compatibility, particularly with respect to the relation between cue signals and the cued *responses.* There is a direct spatial correspondence between cue signals and the locations of the pointing responses, whereas the relation with the precued naming responses relies on a less compatible symbolic translation of the cue signals, which might well have decreased the speed and extent to which the system can respond to precuing. Therefore, the main aim of experiment 2 was to vary S–R compatibility, while holding cue compatibility constant, while experiments 3 and 4 investigated possible effects of cue compatibility.

A second possible dimension of task difference that may have caused the differential effects of precuing is response specificity: within a given subset of cued alternatives, the differences among the naming responses are far greater than the differences among the pointing responses. In other words, the cued naming responses are more *specific*. Response specificity is inversely related to the extent to which responses have a common vector. The cued pointing responses were spatially adjacent and relatively a-specific, and therefore they may have been more easily prepared in advance. In contrast, the cued naming responses are more specific, which could have impaired selective advance preparation. Thus, the differential effects of precueing may have been caused by response specificity. Sanders (1980) has proposed a linear stage model in which response specificity affects response programming rather than response decision. This was based upon evidence that the effect of response specificity interacts with that of relative S–R frequency while it is additive with the effect of S–R compatibility (Sanders 1970). Therefore, an additional aim of experiment 2 was to test the hypothesis that precuing differentially affects response programming, operationalized as response specificity.

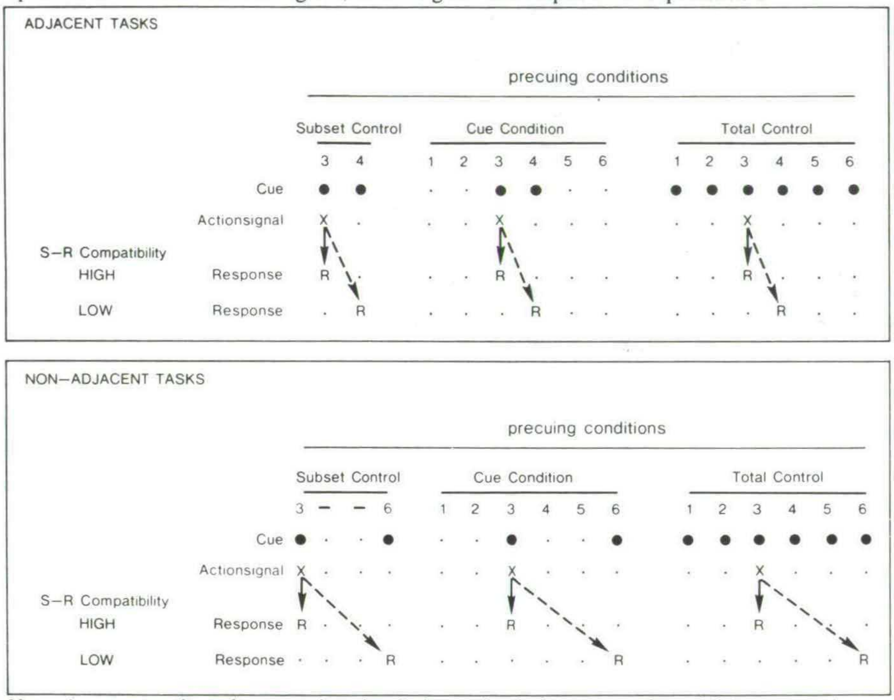
Experiment 2

Experiment 2 provides a further test of three possible explanations of the differential precuing effects, as found in experiment 1. In short, effectiveness of precuing may be enhanced by either one of three factors: (a) S–R compatibility, (b) cue compatibility (i.e., of cues and responses), and (c) a lack of response specificity.

Effects of precuing were tested within the *same* response mode, namely, in a pointing task. Conditions of high and low S–R compatibility were established by employing *congruent* and *incongruent* spatial mappings of action signals and key pressing responses. Hypothesis (a) predicts that S–R compatibility affects the precuing effect (as in the naming task of experiment 1). Hypothesis (b) predicts optimal effects of precuing in all conditions, as long as pointing responses have a compatible relation to the cue signals. Hypothesis (c) states that the effect of precuing is inversely related to response specificity. Thus, the precuing advantage should decrease when there is more specificity among the cued responses. Precuing a pair of adjacent responses decreases response specificity to a greater extent than precuing non-adjacent responses. Therefore, a condition of high response specificity was established by precuing responses at *non-adjacent* locations within the array. Precuing of *adjacent* locations, as in experiment 1, constituted a condition of low response specificity.

The signal–response mappings in the various conditions are illustrated in table 3. Four experimental tasks were established, by orthogonal variation of adjacency and S–R compatibility. A 6-choice pointing task was used as in the previous experiment. Effects of PAI were assessed with regard to reductions of six to two alternatives, since

Table 3
Spatial relations between cue signals, action signals and responses in experiment 2.



Note: As an example, only one action signal alternative is shown, together with its appropriate cue lights. Solid arrows: high S–R compatibility; dashed arrows: low S–R compatibility.

the results of experiment 1 indicated that such a reduction provides the most critical test of precuing.

Method

Experimental tasks

Again, PAI consisted of two cue lights, 300 msec in advance of the action signal. An action signal in the bottom row could only appear at one of the cued positions (see table 3).

Adjacent conditions. The condition of *high* S–R compatibility replicated the 6-choice pointing task of experiment 1 (including a cue condition '6–2', a 2-choice subset control and a 6-choice total control). Thus, in the cue condition, the cued subset was located either at positions 1 and 2, 3 and 4, or 5 and 6. A high level of S–R compatibility always implied an identical location of action signal and target key. The condition of *low* S–R compatibility required subjects to press keys 2,1,4,3,6,5 in response to action signals 1,2,3,4,5,6. For the cue condition, this meant that one of the two positions that were cued contained the action signal while the other cued position identified the target. In other words, the target key was not at the location of the action signal but yet, the target position was cued by a cue light at the identical location. Therefore, cue compatibility was fixed at a high level. In the 6-choice control condition, all six cue lights were presented. In the 2-choice control condition, each pair of cue lights was presented in blocks of trials. (See also table 3.)

Non-adjacent conditions. PAI consisted of two cue lights appearing either at positions 1 and 4, or 2 and 5, or 3 and 6. Under *high* S–R compatibility, the correct response had the same location as the action signal. (This implies that the 6-choice condition was identical to the one in the adjacent task, since in this case non-adjacency did not apply.) With *low* S–R compatibility, the signals 1–6, required a response on key 4,5,6,1,2,3, respectively (see table 3). This S–R mapping implies that there was always a cue light at the same location as the target. This ensured a fixed high level of cue compatibility, as in the adjacent conditions.

The experimental set-up and apparatus approximated the six-alternative pointing condition of experiment 1. The experiment was run under control of a LSI-11/02 computer (Digital).

Procedure

Each subject participated in the three Precuing conditions in all four tasks. Adjacency and S–R compatibility were varied orthogonally across four sessions. Two sessions were run on each of two consecutive days. Half of the subjects were run under different levels of S–R compatibility on separate days, while adjacency was varied between sessions within each day. For the remaining subjects adjacency was varied across days while S–R compatibility was varied between sessions within each day. The order in which the two levels of each of these variables was run was counterbalanced across subjects. Within each session a separate block of trials was run for the 2-choice condition, the cue condition and the 6-choice condition, in that order for half of the subjects, and in the reversed order for the other half. The order was fixed across sessions.

Within sessions, each block of trials consisted of 12 practice trials for each spatial position of the action signal, followed by 18 experimental trials per position. Positions were pseudo-randomized within a run of 36 trials. Within each run, each action signal alternative was followed once and only once by each alternative (Durup 1967). Runs of trials were separated by breaks of about 1 min, in which the subject received knowledge of results. A break of about 10 min separated the two sessions on one day. Further details were identical to those of experiment 1.

Subjects

Sixteen male and female students from Tilburg University, ages between 18 and 29, participated in the experiment. All subjects employed the index finger of their preferred hand. They were paid a fixed sum with the provision that if error rate exceeded 5% within a trial block, there was a penalty of 10 cents per error.

Results

Fig. 2 presents mean RTs of correct trials for each task and Precuing condition, averaged across subjects. Errors of commission were incidental, and never exceeded 2%, although error rates increased as a function of task difficulty.

Mean RTs and further analyses were based on a restricted data set, in which RTs of less than 70 msec were excluded (premature responses), as well as trials with extremely large movement times, in order to avoid effects of RT–MT trade-off. For this purpose,

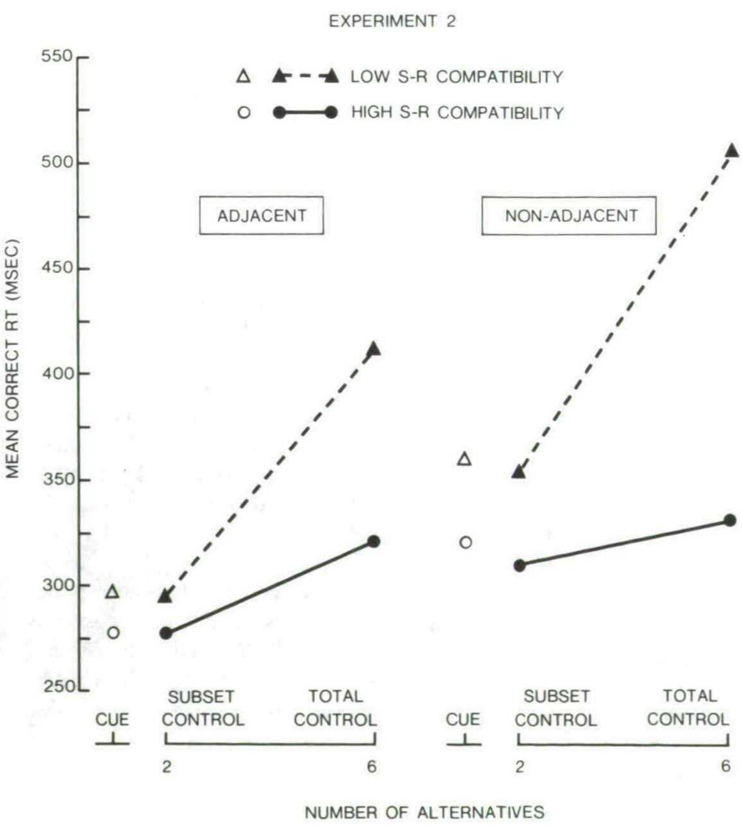


Fig. 2. Mean reaction time (RT) of correct responses in experiment 2, for adjacent (left panel) and non-adjacent (right panel) tasks. Cue conditions: open symbols; subset control and total control conditions: filled symbols.

a maximal MT criterion was calculated for each subject in each of the four tasks. (See appendix for details.) MT criteria averaged 313 msec. In the restricted data set, mean MT hardly differed among experimental conditions (range 162–178 msec). Hence, the RT-data can be considered as free of differential effects of RT–MT trade-off.

Separate (2 × 3) ANOVAs were performed on the adjacent tasks and the non-adjacent tasks, on individual mean RTs, with factors S–R compatibility and Precuing conditions (i.e., 6-choice, 2-choice and cue condition). In the adjacent tasks, both main effects and their interaction were significant; S–R compatibility: $F(1,15) = 51.0$, $p < 0.001$; Precuing: $F(2,30) = 118.7$, $p < 0.001$; interaction S–R compatability × Precuing: $F(2,30) = 62.3$, $p < 0.001$.

Similar results were obtained in the (2 × 3) ANOVA for the non-adjacent tasks. Both main effects and the interaction were significant; S–R compatibility: $F(1,15) = 89.4$, $p < 0.001$; Precuing: $F(2,30) = 90.2$, $p < 0.001$; interaction S–R compatibility × Precuing: $F(2,30) = 114.4$, $p < 0.001$.

Simple effects of Precuing conditions at each level of S–R compatibility were tested by way of simultaneous test procedures (Betz and Levin 1982). In the adjacent tasks, significant differences ($p < 0.05$) were only found between mean RTs of the 6-choice and 2-choice controls and between the 6-choice and the cue condition, indicating a maximal precuing effect at both levels of S–R compatibility. (*MS-error* = 278.4, $df = 30$; i.e., *MS* of the term Precuing × Compatibility × Subjects).

Similar comparisons among Precuing conditions in the non-adjacent tasks, and at the *low* level of S–R compatibility, showed also significant differences between 6-choice and 2-choice controls and between the 6-choice and cue condition (*MS-error* = 444.3), indicating a maximal precuing effect. However, no significant differences among Precuing conditions were observed in the non-adjacent task with *high* S–R compatibility.

The interactions involving the effect of the adjacency factor were tested in a (2 × 2 × 2) ANOVA on individual mean RTs, with factors Adjacency, S–R compatibility and Precuing conditions. The Precuing factor was restricted to the 2-choice control and the cue condition, since the Adjacency factor does not apply to the 6-choice control condition. [1] The main effects of S–R compatibility and Adjacency were significant ($F(1,15) = 21.3$, respectively 62.8, $p < 0.001$ in both cases), as well as the interaction between the effects of Adjacency and S–R compatibility ($F(1,15 = 7.0$, $p = 0.02$). Neither the main effect of Precuing, nor any of the interactions involving effects of Precuing were significant, indicating that precuing effects were optimal in all four tasks.

Simple effects of Adjacency at each level of S–R compatibility were tested (Betz and Levin 1982). Mean RT in the non-adjacent task was significantly larger than in the adjacent task, at each level of S–R compatibility. A similar test between mean RT of high and low S–R compatibility, at each level of Adjacency, indicated a significantly

[1] In the two compatible tasks the 6-choice condition is identical, regardless of adjacency levels. However, in the incompatible tasks, non-adjacency in the 6-choice condition merely implies a greater distance between the signal and the response key. Therefore, the change from adjacent to non-adjacent in the incompatible 6-choice condition results in a further decrease of S–R compatibility (see table 3).

larger mean RT for low S–R compatibility, but only in the non-adjacent condition ($p < 0.05$, $df = 15$, MS-*error* = 562.5, i.e., *MS* of the term Adjacency × S–R compatibility × Subjects).

Discussion experiment 2

In contrast to experiment 1, the effects of precuing and S–R compatibility were independent. In all four tasks of experiment 2, the effect of precuing was maximal, despite large effects of S–R compatibility. As already proposed, changing the response mode in experiment 1 from pointing to naming, has a dual consequence: it lowers the level of S–R compatibility *and* of cue compatibility. Thus, precuing in the naming task may require a more complex and time-consuming translation mechanism from cues to responses, causing a smaller effect of precuing. In experiment 2 the cue–response relation was held constant and was highly compatible, since the pointing responses were always spatially congruent with the cue lights. Consequently, experiment 2 showed optimal precuing effects. Therefore, experiments 3 and 4 will provide tests of the hypothesis that cue compatibility causes differential precuing effects.

Furthermore, the effectiveness of precuing was independent of response specificity, despite a clear main effect of response specificity. As argued, precuing a pair of adjacent responses decreases response specificity to a greater extent than precuing non-adjacent responses, since adjacent responses have more of a common vector. The same effects of precuing are observed with low and high response specificity (i.e., adjacent and nonadjacent positions, respectively). This is best demonstrated at a fixed level of *high* S–R compatibility. First, there was a clearcut effect of response specificity, since mean RT in the compatible adjacent 2-choice condition (277 msec) was significantly smaller than in the non-adjacent case (312 msec). Yet, the corresponding cue conditions were as fast as these 2-choice conditions at either level of adjacency. [2] Sanders (1970, 1977) has suggested that response specificity affects a 'response programming' stage, which is subsequent to the stage of response decision. Hence, according to the additive factor logic, precuing does not seem to affect response programming.

Thus, the evidence so far suggests that precuing does not affect information processing stages prior to or beyond the stage of response decision: the dependence of precuing effects on response-related factors despite identical signal configurations in experiment 1 argues against a perceptual effect, while the independence of adjacency in experiment 2 excludes at least one plausible motor stage.

[2] A similar comparison between precuing effects of the adjacent and non-adjacent condition at the level of *low* S–R compatibility is less decisive, since it may be argued that a change from adjacent to non-adjacent S–R pairs also implies a confounded further decrease of S–R compatibility. Yet, in the low compatibility conditions, precuing effects remain maximal, irrespective of the adjacency level, thus supporting the conclusions above.

Experiment 3

Effects of precuing were examined in a 6-choice pointing task under a high and a low level of both cue compatibility and S–R compatibility. Both dimensions of cue compatibility were covaried, that is, the compatibility of the relation between cue and action signal and between cue and response were simultaneously either high or low. (In experiment 4, these dimensions were separated.) S–R compatibility and cue compatibility were varied orthogonally, resulting in four experimental 'tasks'. For convenience these tasks will be termed as Hi(SR)–Hi(CU) for a high level of both types of compatibility, Hi(SR)–Lo(CU) for a high level of S–R compatibility and a low level of cue compatibility, etc. Again, a triplet of Precuing conditions was used, namely, the control conditions '6-choice' and '2-choice', and the cue condition '6–2'.

Method

The same array of six lights and keys was employed as in the previous experiments. The array was divided in three imaginary sections, each of two adjacent locations each, i.e., positions (1,2), (3,4) and (5,6). The cue lights were always presented in one section of the top row, and thus always pointed to two spatially adjacent S–R pairs. Again, the cue signal occurred 300 msec in advance of the action signal.

In the condition of high cue compatibility, the two cued S–R pairs were located within the *same* section as the cue, for example, cue lights 1 and 2 cued action signals 1 and 2. Low cue compatibility was established by a horizontal displacement of the two cue lights relative to the cued S–R pairs (see upper half of table 4). For half of the subjects, the incompatible mapping between the cue lights and the S–R pairs was, in order, (1,2) – (3,4), and (3,4) – (5,6) and (5,6) – (1,2). For the other subjects the mapping was (1,2) – (5,6), and (3,4) – (1,2) and (5,6) – (3,4).

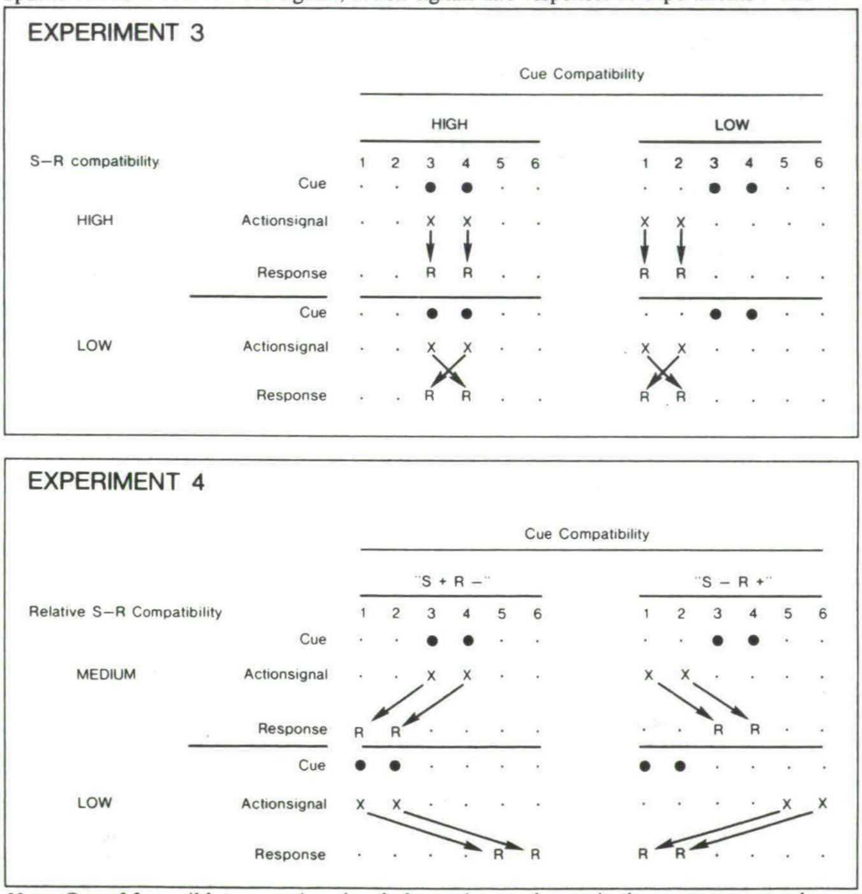
In the condition of high S–R compatibility, the response key always had the same location as the action signal. A low level of S–R compatibility was established by crossing the action signals and responses *within* one section (i.e., signals 1,2,3,4,5,6 required respectively response 2,1,4,3,6,5. See upper half of table 4).

Procedure and design

All subjects participated in the four compatibility 'tasks' and, for each task, in a triplet of Precuing conditions. The subset control and the cue condition were replicated in each of the four tasks, whereas the total control condition was logically identical across cue compatibility and, hence, it was only run at a high and a low level of S–R compatibility.

Two sessions were run on consecutive days. Two of the tasks were assigned to each session. For half of the subjects, S–R compatibility was varied across sessions, while cue compatibility was varied between the first and second half of a daily session. Conversely, for the remaining subjects, cue compatibility was varied across sessions, while S–R compatibility was varied within sessions. Within each group, the order of high and low level of either type of compatibility was counterbalanced between

Table 4
Spatial relations between cue signals, action signals and responses in experiments 3 and 4.



Note: Out of 3 possible cue–action signal alternatives, only one is shown as an example, together with the 2 cued S–R pairs, each of which occurring with $p = 0.5$. Only cue conditions are shown.

subjects. The order of the Precuing conditions during the first half of a session was '2-choice' (subset control), '6–2' (cue condition) and '6-choice' (total control); this order was reversed for the second half of the session. In each task, one block of trials was devoted to each of the Precuing conditions, preceded by one practice block. In the subset control, each block consisted of 18 trials per position of the action signal, divided into 3 sub-blocks for each section of the array. In the total control and the cue condition, each block consisted of 12 trials per position. Session halves lasted about 50 min and were separated by a 50-min pause. Other details were similar to those of experiment 2.

Subjects

Twelve subjects between 18 and 32 years of age participated in the experiment. They were paid a fixed sum for participation and received an additional 3-cent bonus for each correct response. Two subjects were replaced in the course of the experiment, due to extremely high error rates.

Results

Fig. 3 presents correct mean RTs, averaged across subjects, for the three Precuing conditions in each of the four tasks. Tasks with high and low cue compatibility are shown respectively in the left and right panel. Since cue compatibility was not varied in

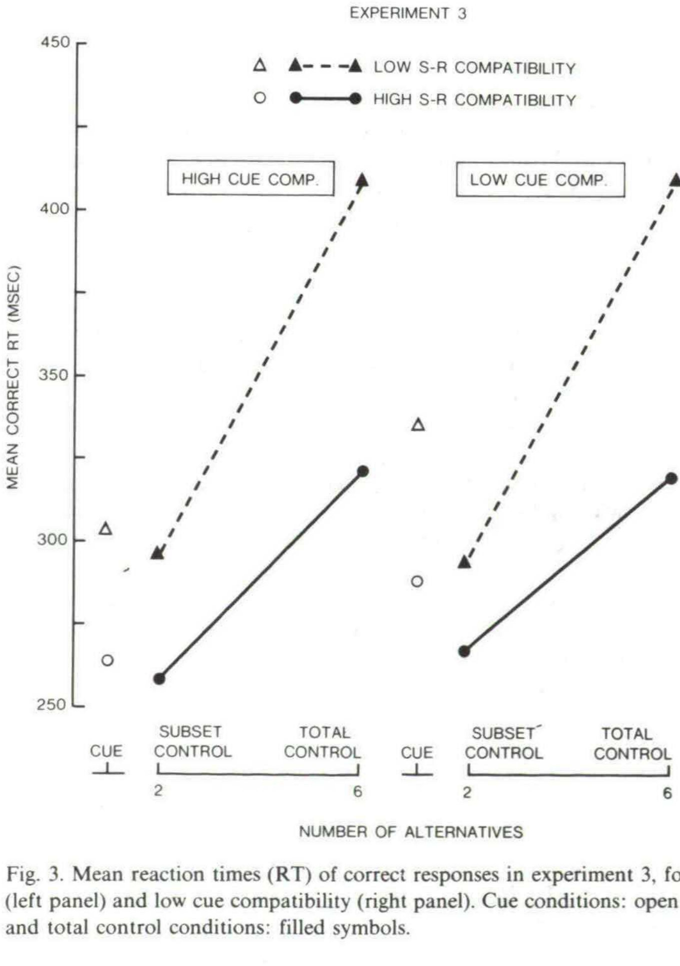


Fig. 3. Mean reaction times (RT) of correct responses in experiment 3, for high cue compatibility (left panel) and low cue compatibility (right panel). Cue conditions: open symbols; subset control and total control conditions: filled symbols.

conjunction with the total control condition, the two means of the total control conditions are shown in both panels.

Mean RTs and further analyses were based on a restricted data set, to avoid effects of premature responses. Maximal MT criteria for each subject and response key were again calculated for each of the four tasks, as in experiment 2. The MT criteria hardly differed among the four tasks with an overall average of 220 msec. 2.6% of the trials were thus excluded . Mean MTs hardly differed among conditions (overall average 125 msec, range 117–134 msec). Hence the RT data can be considered as free of RT–MT trade-off.

The most striking feature of the results in fig. 3 is the difference in precuing advantage between high and low cue compatibility. With a compatible cue (left panel), the cue condition is on the average only 6 msec slower than the 2-choice (subset) control condition. This is so for both high and low S–R compatibility. In contrast, with an incompatible cue (right panel), the cue condition is 23 msec and 41 msec slower, for high and low S–R compatibility, respectively.

In order to compare precuing effects among the four tasks, a $(2 \times 2 \times 2)$ ANOVA was performed on individual mean RTs of the subset control and cue conditions, with factors S–R compatibility, Cue compatibility and Precuing (subset control vs cue condition). Significant main effects were found for the effects of S–R compatibility ($F(1,11) = 40.5$, $p < 0.001$), and Precuing ($F(1,11) = 9.6$, $p < 0.001$), whereas Cue compatibility only reached marginal significance ($F(1,11) = 3.6$, $p = 0.08$). The only significant interaction was found between the effects of Precuing and Cue compatibility ($F(1,11) = 8.1$, $p = 0.01$). The interaction between effects of Precuing and S–R compatibility was far from significant ($p = 0.19$).

Simple effects of cue compatibility were tested by way of simultaneous test procedures (Betz and Levin 1982), (*MS-error* = 449.2, $df = 11$, i.e., *MS* of the interaction Precuing × Cue compatibility × Subjects). Cue compatibility did produce significant differences between cue conditions, at either level of S–R compatibility ($p < 0.05$), indicating slower responding for incompatible cueing. In contrast, cue compatibility did not affect the subset controls.

Likewise, simple effects of Precuing were tested at each level of cue compatibility. A significant difference between the subset control and cue condition was found only at the level of *low* cue compatibility, indicating a suboptimal precuing effect. In the task Lo(SR)–Lo(CU) this difference of mean RTs averaged 41 msec, whereas in the task Hi(SR–Lo(CU) this difference was only 23 msec, suggesting an improvement of the suboptimal precuing effect for high S–R compatibility. To check whether this latter difference of 23 msec was still substantially larger than the 6 msec difference in the task Hi(SR)–Hi(CU), a (2×2) ANOVA was performed on individual mean RTs of the subset control and cue condition, within the high level of S–R compatibility, with factors Precuing (subset control vs cue) and cue compatibility. Both main effects were significant; Cue compatibility: $F(1,11) = 7.0$, $p = 0.02$; Precuing: $F(1,11) = 5.0$, $p =$ 0.04. The interaction Precuing × Cue compatibility reached marginal significance ($F(1, 11) = 3.2$, $p = 0.09$).

S–R compatibility and Number of alternatives (2 vs 6) showed the expected interactive effects in a (2×2) ANOVA on individual mean RTs of the 2-choice controls and 6-choice controls. (The analysis comprised only the two tasks with high cue compatibility, as the 6-choice controls were identical for high and low cue compatibility.) Both main effects and the interaction were significant. (In all tests $F(1, 11) > 50.0$, $p < 0.001$.)

Errors of commission averaged 0.9% across all conditions. These errors were more frequent in the cue conditions (1.2%) and in the total control conditions (1%) and, comparing among the four tasks, errors tended to be more frequent in incompatible tasks, i.e., 0.5% in the task Hi(SR)–Hi(CU); 0.9% in Hi(SR)–Lo(CU); 1.2% in Lo(SR)–Hi(CU); 0.8% in Lo(SR)–Lo(CU).

Discussion experiment 3

Cue compatibility had a substantial influence on the effectiveness of precuing, in the sense that an incompatible mapping of cue-signals onto S–R alternatives reduced precuing effects. As in experiment 2, S–R compatibility did not influence the effect of compatible precuing. Yet, a low level of S–R compatibility seems to further reduce the advantage of *in*compatible precuing: the cue condition was 23 msec slower than the subset control with high S–R compatibility and this disadvantage increased to 41 msec with low S–R compatibility.

The present results support the tentative explanation for the suboptimal precuing effects observed in the naming task of experiment 1. The use of naming responses not only reduced the compatibility between action signals and responses, but also between cues and S–R pairs, so that the reduction of the precuing advantage in experiment 1 was probably caused by cue incompatibility. Yet, it should be realized that in experiment 1 cue compatibility was only distorted with respect to the response and not to the action signal.

The question remains, therefore, to what extent the effect of cue compatibility depends on the spatial relation between the cue and action signals, or on the relation between the cue signal and the responses. In experiment 3, cue compatibility was varied simultaneously on these dimensions. From the vocal data of experiment 1 it is expected that the relation between cue signal and *response* alternatives is at least a major contributor, as it was precisely on that dimension that the cue signals in the naming task of experiment 1 were less compatible than in the pointing task. Experiment 4 investigated to what extent the two dimensions of cue compatibility modulate the effect of precuing.

Experiment 4

Two experimental tasks were established: in one task, the relation between cue and action signals is compatible, while the relation between cue and responses is incompatible (*task 'S + R − ')*. In the second task, the levels of cue compatibility were reversed, which resulted in a low level of compatibility between cues and action signals and a high level of compatibility between cues and responses (*task 'S − R + '*). (In contrast, experiment 3 varied cue compatibility simultaneously on both dimensions and, hence, in the present notation, experiment 3 compared a 'S + R + ' task and a 'S − R − ' task.) In each task the effect of precuing was examined by comparing performance between two Precuing conditions: the subset control ('2-choice') and the cue condition ('6–2'). The experiment did not include a 6-choice control condition as it was deemed irrelevant for the present purpose. Since the S–R mappings were always spatially incongruent, all S–R pairs were of a relative low level of S–R compatibility. Yet, S–R compatibility was varied across a 'low' and a 'medium' level, as the horizontal displacement of an S–R pair spanned either 4 or 2 locations of the array (see lower section of table 4).

Method

The apparatus and experimental set-up were identical to experiment 3, except for differences in the spatial mapping of (a) cue lights to action signals and (b) action signals to responses. (See table 4.) Again, the horizontal array of six lights and keys was divided in three imaginary sections of two adjacent locations each, i.e., sections (1,2), (3,4) and (5,6). The cue signal always consisted of two lights from one section.

In the *'S + R − ' task,* the section in which the action signal occurred always coincided with the section of the cue lights, thus representing a compatible relation between cue and action signal (S +). However, the relation between the cue signal and the cued responses was incompatible (R −), since the locations of the responses were horizontally displaced relative to the cue signal (as well as to the action signal). In the *'S − R + ' task,* the location of the cue signal always coincided with the cued responses (R +), whereas the section of the cued action signals was horizontally displaced (S −).

In both tasks, the same mappings of action signals to responses were used. However, there were two kinds of mappings in order to control for asymmetry. In the 'A-mapping', the sections of action signals (1,2), (3,4) and (5,6) were respectively mapped on the response sections (5,6), (1,2) and (3,4), whereas in the "B-mapping' the response sections were respectively (3,4), (5,6) and (1,2). The relative positions *within* the signal and response sections were congruent, so that the signals 1,2,3,4,5,6 mapped to responses *5,6*,1,2,3,4 (A-mapping) and to 3,4,5,6,*1,2* (B-mapping). With either way of mapping, four out of six S–R pairs were of *medium* S–R compatibility, since the responses were displaced over only *two* locations relative to the action signals (e.g., signals 3 and 4 to keys 1 and 2). The two remaining pairs were of *low* S–R compatibility (see italicized responses in the above enumeration), since these pairs had a displacement of *four* locations (e.g., signals 1 and 2 to keys 5 and 6). In this way, S–R compatibility was an auxiliary variable.

Procedure and design

Each of the two tasks was assigned to a separate group of six subjects each. Within each group, the A- and B-mapping of action signals to responses were randomly assigned to half of the subjects. Each subject participated in one session. In a session one block of practice trials was run in the subset control condition, followed by two practice blocks in the cue condition. After practice, the subset control and the cue condition were run in the order ABAB or BABA for one half of the subjects within a group, in two 40-min episodes, with a midway break of about 40 min. The subset control condition was run twice in one block of trials, consisting of three sub-blocks for each section of the array. Each sub-block contained 18 trials for each action signal, and it was preceded by 15 warm-up trials. The cue condition was run twice in four consecutive trialblocks at a time. The first block was for warming up. Each block contained 12 trials for each action signal. Other details approximated those of experiments 2 and 3.

Subjects

Twelve subjects, between 20 and 34 years of age, without previous experience in reaction tasks, participated in the experiment. They were paid as in experiment 3. Two subjects, assigned to the 'S − R + ' task, were replaced in the course of the experiment due to extremely high error scores.

Results

The same data selection was performed as in the previous experiments, by application of maximal MT criteria for each subject and response key. These criteria hardly differed among tasks and averaged 281 msec. About 3% of the trials were thus excluded. Mean MTs of the selected data averaged 137 msec and hardly differed among the four conditions (range 133–142 msec). Hence, the RT data can be considered as free of RT–MT trade-off.

The left panel of table 5 presents correct mean RTs for the subset control and cue condition in each task, averaged over subjects and all keys (i.e., pooled across medium and low S–R compatibility). The difference between cue and subset control condition is also displayed, as it indicates the extent to which precuing falls short of being maximally effective. Table 5 (left panel) clearly shows that cue compatibility strongly affected the size of the precuing effect: precued responses in the 'S + R − ' tasks were 63 msec faster than in the 'S − R + ' tasks, and this was caused entirely by higher precuing effectiveness, as reflected in the Cue–Control difference score (65 vs 130 msec).

A (2×2) ANOVA was performed on individual mean RTs, with factors Cue compatibility ('S + R − ' vs 'S − R + '), nested within subjects, and Precuing (subset control vs cue condition) as a repeated factor. Of the main effects only Precuing was significant ($F(1,16) = 33.7$, $p < 0.001$). There was also a moderate significance for the interaction of the effects of Precuing conditions and Cue compatibility ($F(1,16) = 3.8$, $p = 0.06$), reflecting the large effect of cue compatibility in the cue condition in favor of condition 'S + R − ', and the absence of such an effect in the subset control condition.

The above analysis of the joint effects of precuing and cue compatibility was also

Table 5
Mean reaction times (msec) in experiment 4.

	Overall		S–R compatibility			
			Medium		Low	
Task:	'S+R–'	'S–R+'	'S+R–'	'S–R+'	'S+R–'	'S–R+'
Subset control	332	330	325	322	347	345
Cue condition	397	460	389	447	415	499
Difference cue – control	65	130	64	125	68	154

performed separately for the medium and the low level of S–R compatibility (as defined by the horizontal displacement of the response key relative to the action signal). The middle and right panel of table 5 present mean RTs for the medium and the low level of S–R compatibility. Both levels show the same pattern of effects as in the overall analysis above: cue compatibility only affects the cue condition. Secondly, conditions 'S – R + ' produces a larger cue–control difference than condition 'S + R – ' (i.e., a *smaller* precuing effect) and this contrast is amplified in the condition of low S–R compatibility.

These observations were substantiated in two (2 × 2) ANOVAs, for each level of S–R compatibility, on individual mean RTs, with factors Precuing (cue vs subset control) and cue compatibility ('S + R – ' vs ('S – R + '). In the analysis at the *medium* level of S–R compatibility, there was a significant main effect of Precuing conditions ($F(1,16) = 33.7$, $p < 0.001$) and a moderately significant interaction between the effects of Precuing and Cue compatibility ($F(1,16) = 3.5$, $p = 0.7$). In the analysis at the *low* level of S–R compatibility, the main effect of Precuing and the first-order interaction were both highly significant (Precuing: $F(1,16) = 32.4$, $p < 0.001$; Precuing × Cue compatibility: $F(1,16) = 4.8$, $p = 0.04$). In addition, the effect of Cue compatibility reached moderate significance ($F(1,4) = 6.2$, $p = 0.07$). Hence, the low level of S–R compatibility seems to amplify the interactive effects of Precuing and Cue compatibility.

Errors of commission averaged 4.2% across all conditions. These errors were more frequent in the 'S – R + ' task (subset control 2.3%, cue condition 8%) than in the 'S + R – ' tasks (subset control 0.8%, cue condition 5.6%). Hence, error rates are positively related to mean RTs, suggesting absence of speed–accuracy trade-off.

Discussion experiment 4

Both dimensions of cue compatibility appear to be important determinants of precuing effectiveness, since a low level at either one of these dimensions causes the cue condition to be substantially slower than the subset control, while the cue condition was as fast as the subset control in experiment 3, in which high levels existed on both dimensions of cue compatibility (S + R +).

Secondly, a comparison between the cue condition in the 'S + R + ' task of experiment 3 and the present experiment shows that cue–action signal incompatibility is more detrimental than cue–response incompatibility. Also, the decrease of S–R compatibility amplifies this greater detriment, as is shown by the Cue–Control difference scores in table 5 (middle and right panels). An effect of S–R compatibility on these difference scores is only observed in the 'S–R + ' task. Thus, advance processing in response to the cue is vulnerable to a decrease of S–R compatibility *only* in case of an incompatible mapping of cues onto *action signals*. This finding confirms and further specifies the observation of experiment 3 that a decrease of S–R compatibility amplifies the disadvantage caused by a decrease of cue compatibility on both dimensions. The dependence of the precuing effect on both S–R compatibility and cue–action signal compatibility supports the hypothesis that precuing and cue compatibility affect common processes in the response decision stage.

A comparison between experiments 3 and 4 also reveals that a simultaneous decrease of cue compatibility on both dimensions (experiment 3) is less detrimental than a decrease on either one dimension (experiment 4): in experiment 3, with the incompatible cue (task 'S – R – '), the cue condition was 23 msec and 41 msec slower than the subset control (for high and low S–R compatibility, respectively), whereas in experiment 4 this difference ranged between 64 and 154 msec. (See table 5.) Hence, decreasing one dimension of cue compatibility made precuing more imperfect than decreasing two dimensions. This pattern of results suggests that the two dimensions of cue compatibility are intricately related and affect common processes.

It is also of interest that precuing is less disturbed in the 'S + R – ' task than in the 'S – R + ' task. This finding argues against locating precuing effects in motor stages. This view would predict a relative advantage for the 'S – R + ' task, since a compatible cuing of the responses should provide a better opportunity for advance response programming. This is in line with the results of experiment 2 that already argued against response programming as the locus of precuing effects.

The suboptimal precuing effects in the 'S + R – ' task correspond to the slight effects observed in the vocal task of experiment 1. In both cases the partial effects are caused by a low level of cue–response compatibility. Yet, the precuing effects in the 'S + R – ' task are larger than in the vocal task, which may reflect a lower degree of cue–response compatibility in the naming task.

General discussion

The main points of the present study can be summarized as follows:

(*a*) The extent to which precuing by means of PAI reduces RT, strongly depends on response mode (pointing vs naming), when the characteristics of cue signals and action signals are held constant and compatible in relation to one another (experiment 1). This suggests that advance processing in response to precuing involves processing stages beyond perceptual stages.

(*b*) When the cue signal is compatible with the cued action signals and with the cued pointing responses, precuing results in an optimal reduction of RT. This effect is independent of both S–R compatibility and response specificity (experiment 2).

(*c*) Cue compatibility is a two-dimensional variable: it refers to the relations of the cue with action signals and with responses. Variation of cue compatibility, in the same direction on both dimensions, modulates the precuing effect: decreasing the level of cue compatibility decreases the effectiveness of precuing (experiment 3).

(*d*) The precuing effect depends on both dimensions of cue compatibility, but to a greater extent on cue–action signal compatibility than on cue–response compatibility (experiment 4).

(*e*) Low S–R compatibility amplifies the impairment of the precuing effect caused by decreasing cue–action signal compatibility. No such amplification occurs with the impairment caused by decreasing cue–response compatibility (experiments 3 and 4).

In the light of this evidence, it is concluded that precuing and cue compatibility affect the stage of response decision. Therefore, this study supports recent criticisms (e.g., Reeve and Proctor 1984; Stelmach and Larish 1981; Goodman and Kelso 1980) on movement precuing studies, in which differential precuing effects are explained as reflecting properties of motor programming. This study demonstrates instead that differential precuing effects may arise from variations in cue compatibility, while no evidence was found for the hypothesis that precuing affects motor stages.

As a prerequisite for a more detailed interpretation of the interactive effects of precuing, S–R compatibility and cue compatibility, it is useful to consider a current model of decisional processing, according to which a search is made through a limited capacity memory stack, holding a representation of the stimulus and response arrays (e.g., Theios 1973, 1975; Logan 1980). This search produces a representation of the appropriate response which is to be translated into overt behavior in subsequent motor stages. The duration of the search and decision process depends on the strength and number of S–R associations in the memory stack, and on the discriminability or accessibility of the elements within the buffer (e.g., John 1969).

In such a model, precuing may facilitate memory search by changing some properties of the stored information in advance of the actual search. For instance, precuing may produce search priorities for cued S–R alternatives or, at least, raise their accessibility. Cue signals may be more or less compatible to a central processing code (cf. Wickens et al. 1983). Consequently, cue compatibility may affect the ease with which search priorities of the memory buffer are rearranged in response to precuing. Thus, precuing may not affect the associational strengths, but rather the organization of the search through the memory set.

This search model also accounts well for the fact that both types of cue compatibility modulate the effectiveness of precuing. Obviously, a high cue–response compatibility improves the priorities of search for relevant responses, while high cue–action signal compatibility improves the search through a list of signal representations for a match with the 'template' of the actually presented action signal. However, the finding that advance processing is vulnerable to a decrease of S–R compatibility in case of cue–action signal incompatibility, but not in case of cue–response incompatibility is not easily conciliated with the commonly accepted view that the directionality of the response decision process is from signal to response representations. Instead, the present results suggest the opposite direction, namely a serial search through a list of response representations. To be more specific, it may be assumed that at each step in this search (i.e., for each response representation) the appropriate action signal is looked up, followed by a match or mismatch with the 'template' of the actual action signal. This process is repeated until a match occurs. This conjecture not only explains why a decrease of S–R compatibility amplifies the disadvantage caused by low cue–action signal compatibility, it also accounts for the independent effects of precuing and S–R compatibility under high levels of cue compatibility, as in experiment 2.

In addition the present results cast some doubt on the generality of Duncan's (1977, 1978) proposal that response decision is not based on a list of individual S–R associations but rather on transformational rules, generating entire sets of S–R alternatives. Rule-governed relations (from signals to responses) were proposed to explain effects of consistent vs inconsistent S–R mappings. However, the present findings on cue compatibility underline the importance of individual S–R associations: firstly, for adequate presetting of decisional processes, individual signal and response representations should be easily accessible. Secondly, the present view does not support the S–R directionality as implied in these rules.

The present finding that cue compatibility affects response decision processing also casts a different light on a recent study by Meyer et al. (1984) in which effects of precuing were interpreted as reflecting response preparation. These investigators used relatively incompatible cues, i.e., words vs non-words signalling right- or left-hand responses, with a precuing interval similar to ours (about 285 msec) and also a longer interval (805 msec). With the longer interval, larger precuing effects generally occurred, but more importantly, in a number of trials this increase was more pronounced for some of the subjects. It was proposed that, with either interval duration, precuing activates motor programming, whereas with a long precuing interval a subsequent 'program loading' stage is also activated, thus resulting in multi-stage response preparation. The present study rather suggests that the result of Meyer et al. can be explained by differential degrees of presetting the response decision stage as a function of cue compatibility. Longer intervals may have amplified these differential effects.

Appendix

A maximal MT duration was calculated for each of the four tasks as follows. After inspection of individual MT distributions, the MT criterion was defined for each subject and each response key by adding 150 msec to the median MT in the subset control condition. This condition was choosen since it was considered to be the least vulnerable to RT–MT trade-off. All trials in which MT exceeded the criterion were discarded. Individual criteria, averaged across conditions ranged between 256 and 361 msec. Hence, it seemed worthwhile to apply criteria based on individual MT distributions. The criteria were virtually equivalent among the four tasks, but they were a U-shaped function of key positions (ranging between 298 and 333 msec), reflecting the distances from the release key.

Application of the MT criteria resulted in 2.6% exclusions in the adjacent compatible task, 3.7% in the non-adjacent compatible task, 4.4% in the adjacent incompatible task and 7.7% exclusions in the non-compatible non-adjacent task. For each task, the percentage of exclusions tended to increase across Precuing conditions, in the order (a) subset control, (b) cue condition, (c) total control. However, the differences among these conditions never exceeded 4%.

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SAMENVATTING
SUMMARY

Samenvatting

Dit proefschrift behandelt de vraag hoe in korte-duur geheugentaken informatie uit het menselijk geheugen wordt opgehaald. In deze taken wordt een reeks gegevens eenmaal ter inprenting aangeboden en -- na het verstrijken van een "retentie-interval" van betrekkelijk korte duur -- dienen de gegevens te worden gereproduceerd of herkend.

Volgens gangbare opvattingen uit de cognitieve psychologie worden de te onthouden gegevens in een geheugencode omgezet en opgeslagen. De opgeslagen informatie dient gedurende het retentie-interval te worden vastgehouden. Wanneer men zich de gegevens poogt te herinneren wordt de opgeslagen informatie opgehaald zodat deze beschikbaar is voor reproductie van de gegevens of voor herkenning. Zowel bij het coderen, het opslaan, alsook bij het ophalen van de gegevens, kunnen de onderliggende processen worden verstoord, hetgeen tot verminderde geheugenprestaties leidt. In deze cognitief-psychologische benadering wordt het menselijk geheugen beschouwd als een informatieverwerkend systeem. De ophaalprocessen van het geheugen worden daarbij opgevat als een cognitieve activiteit die grotendeels verloopt zonder dat daarvan een bewuste ervaring ontstaat. Deze ophaal- en zoekprocessen zijn dus niet toegankelijk voor introspectie. Daarom wordt getracht om de processen, die aan een goed functionerend menselijk geheugen ten grondslag liggen, te bestuderen door middel van experimenteel psychologisch onderzoek.

In de literatuur over eerder onderzoek naar de ophaalprocessen van het geheugen wordt de geheugenprestatie doorgaans uitgedrukt in het percentage correct gereproduceerde gegevens. Met andere woorden, het geheugen wordt onderzocht door het falen ervan vast te stellen. In dit proefschrift wordt een andere benadering gekozen, gericht op de processen die tot correcte herkenning of reproductie leiden. Deze aanpak poogt de eigenschappen van de <u>succesvolle</u> geheugenprocessen te ontdekken door de duur van deze processen te meten en door vast te stellen welke omstandigheden en taakeisen de procesduur beinvloeden.

In het merendeel van de experimenten uit dit proefschrift wordt de "positionele-probe techniek" gebruikt: Na aanbieding van een te onthouden lijst items wordt een "positionele probe" (sonde) aangeboden waarmee de seriele positie van het te reproduceren item in de lijst wordt aangegeven. Zodoende is het mogelijk de reactietijd (RT) te meten van de vocale reproductie van een enkel item. RT is gedefinieerd als het interval dat verloopt tussen de aanbieding van de positionele probe en de (vocale) response. Aldus kan de duur worden vastgesteld van het ophaalproces dat tot de correcte reproductie heeft geleid.

Onderzoek van de laatste tien à twintig jaar, waarin het falen van het geheugen werd onderzocht, heeft het belang aangetoond van "retrieval-cues". Onder een retrieval-cue wordt verstaan een gegeven dat door het ophaalproces wordt gebruikt om daarmee andere gegevens in het geheugen op te zoeken. Doordat een adequate retrieval-cue informatie bevat die aan het gezochte gegeven gerelateerd is, wordt het gezochte gegeven in het geheugen geactiveerd. Het ophaalproces wordt dus door de retrieval-cues op het gezochte geheugenspoor gericht. In deze visie zijn het verwerven en het beschikbaar blijven van adequate retrieval-cues van doorslaggevend belang voor de herinnering.

De door Sanders (1975) voorgestelde "positionele cueing theorie" beschrijft de retrieval-cues die gebruikt worden bij het herinneren en reproduceren van een eerder ingeprente lijst van opeenvolgend aangeboden gegevens (items). Temporele ankerpunten tijdens de presentatie van de lijst spelen een grote rol bij het vormen van "positionele retrieval-cues" die gekoppeld zijn aan bepaalde seriele posities van de geheugenlijst. De positionele retrieval-cues maken de lijst op deze posities direct toegankelijk voor het ophaal proces. Deze theorie heeft als leidraad gediend voor de opzet van de experimenten die in dit proefschrift worden beschreven.

Het doel van deze studie is daarom het toetsen van enkele hypothesen over ophaalprocessen van het geheugen. De hypothesen zijn afgeleid uit de positionele-cueing theorie (Sanders, 1975). De experimentele methoden die hier worden gebruikt zijn deels gebaseerd op onderzoek door Sanders & Willemsen (1978). Dat onderzoek is een van de eerste studies waarin de duur van de ophaalprocessen wordt onderzocht door het meten van reactietijd in een "probed-recall" taak.

In het huidige onderzoek worden hypothesen getoetst over het presteren in taken waarin het korte-duur geheugen steeds een belangrijke rol speelt. De taken die in deze studie voorkomen, zijn:

(a) een "probed-recall taak"; het herinneren en reproduceren van een enkel item uit een lijst opeenvolgend aangeboden items. De seriele positie van het gevraagde item wordt aangegeven door een lichtsignaal (positionele probe) uit een rij lichtjes. Het linker licht duidt het eerst aangeboden item aan, het tweede licht van links duidt het tweede item uit de geheugenlijst aan, enz. (Hoofdstukken 2-6).

(b) een "geheugen-zoektaak"; het herkennen van een test-item als een van de items uit een eerder aangeboden lijst (Hoofdstuk 7).

(c) een "keuze-reactietaak"; het reageren op een signaal dat deel uitmaakt van een grotere verzameling mogelijke signalen. Op elk signaal moet een unieke reactie gegeven worden; bijvoorbeeld bij elk lichtsignaal uit een rij lichten hoort een aparte drukknop (Hoofdstuk 8).

In een aantal experimenten (Hoofdstuk 2 en 3) worden enkele voorspellingen van de positionele-cueing theorie getoetst. Deze voorspellingen betreffen de effecten van subjectief groeperen van de lijst tijdens presentatie en de effecten van "precueing" van een deel van de lijst, kort voordat de positionele probe wordt aangeboden. Door precueing wordt het aantal mogelijke seriële posities, waarnaar de probe verwijst, kleiner. De resultaten zijn in overeenstemming met de positionele-cueing theorie. Uit de resultaten blijkt namelijk dat groeperen de RT verkort en de fouten vermindert, vooral voor items die twee opeenvolgende lijstdelen begrenzen. Dit kan erop wijzen dat door het groeperen de lijst op een aantal extra posities direct toegankelijk wordt gemaakt.

Precueing heeft een <u>gunstig</u> effect op de RT, terwijl het aantal fouten er niet door wordt beïnvloed. Dit resultaat wijst erop dat precueing het ophaal proces preactiveert. Daardoor wordt de lijst ontsloten op een van de punten van directe toegankelijkheid, en wel reeds voordat de positionele probe wordt aangeboden en dus ook voordat het RT-interval aanvangt. Dit is echter slechts het geval indien het gevraagde item via het gepreactiveerde ophaalproces bereikbaar is. Nadelige effecten van precueing op de RT, alsook op het aantal fouten, treden op indien het gevraagde item niet bereikbaar is via het gepreactiveerde ophaalproces.

In het experiment beschreven in Hoofdstuk 4 wordt de duur van het interval tussen het precueing-signaal en de positionele probe gevarieerd. Naarmate het precue-probe interval langer is, neemt het positieve precueing effect op RT verder toe, terwijl er geen effect op het aantal fouten is, ook niet bij langere intervallen. Deze bevindingen zijn in overeenstemming met de voorspellingen van de positionele-cueing theorie.

In Hoofdstuk 5 worden enkele voorspellingen getoetst betreffende storende effecten op de reproductie veroorzaakt door proactieve interferentie (PI) van een voorafgaande geheugenlijst. In dit experiment worden paren van kort opeenvolgende trials gescheiden door een langer interval. In elk trial wordt een probed-recall test uitgevoerd, nadat een lijst met te onthouden items is aangeboden. Door het langere interval wordt voorkomen dat het trial na het interval bloot zou staan aan PI afkomstig van voorafgaande trialparen. De te onthouden lijsten die in dit experiment worden gebruikt bestaan òf uit een serie medeklinkers òf uit een cijfer-prefix gevolgd door medeklinkers. In het tweede trial van elk trial-paar nemen de RT en het aantal fouten toe ten gevolge van PI. Dit effect is echter beperkt tot het eerste deel van de lijst en dat duidt erop dat tijdens het ophaalproces verwarring optreedt tussen de "primacy" retrieval-cues verbonden met het eerste item van beide lijsten. Deze verwarring veroorzaakt een vertraging of een falen van het ophaalproces. Bovendien wordt een sterker effect van PI gevonden indien in beide lijsten een prefix voorkomt. De prefix in beide lijsten verhoogt de kans op verwarring. Deze resultaten bevestigen de voorspelling van de positionele-cueing theorie.

In Hoofdstuk 6 wordt onderzocht of het PI-effect al of niet gestaag toeneemt over een reeks van zes kort opeenvolgende trials. Ook in dit experiment wordt de RT van probed-recall gemeten. Het experiment onderzoekt de mogelijkheid of een groter aantal voorafgaande trials bijdraagt tot PI dan tot nog toe werd aangenomen op grond van eerder onderzoek. Daarin werd immers alleen de proportie correcte reproductie gemeten. In overeenstemming met eerder onderzoek blijkt evenwel dat het grootste deel van het PI-effect optreedt in het tweede trial. Er is dus geen sprake van een gestaag toenemend cumulatief PI-effect. Het resultaat van dit experiment rechtvaardigt eveneens een conclusie over de relatief lange RTs voor de eerste seriele posities, zoals deze worden gevonden in de experimenten uit Hoofdstukken 2-4. In deze experimenten is de RT voor items aan het begin van de lijst aanzienlijk lager dan voor latere items. De relatief lange RTs in het eerste deel van de lijst kunnen niet zijn veroorzaakt door PI of door langdurige oefening, hoewel in deze experimenten een groot aantal trials in korte opeenvolging werd gegeven. De vraag naar de oorzaak van dit relatieve nadeel voor het eerste lijstdeel kan wellicht door verder onderzoek worden beantwoord.

In Hoofdstuk 7 worden de effecten van groeperen en van precueing onderzocht in een herkenningstaak (geheugen-zoektaak). In deze taak wordt de proefpersoon gevraagd zo snel mogelijk te beslissen of een test-item al dan niet is voorgekomen in een kort tevoren aangeboden lijst. In sommige condities van het experiment wordt deze lijst gegroepeerd, door het inlassen van een korte pauze tijdens de presentatie van de items. Aldus ontstaan door groeperen twee sub-lijsten. In de precueing-conditie wordt een van de sub-lijsten aangeduid als de enige sub-lijst waarin een item kan voorkomen dat met het test-item overeenstemt. De RT voor herkenning van het test-item blijkt een lineair toenemende functie te zijn van de lengte van de lijst, ongeacht het al-of-niet groeperen, of de aan- dan wel afwezigheid van precueing.

Groeperen veroorzaakt een aanzienlijke reductie van de intercept van deze lijstlengte-functies; de helling van de functies blijft daarentegen onveranderd. Precueing van een sub-lijst versterkt het positieve effect van groeperen, doch slechts voor trials waarin een positief test-item wordt aangeboden (d.i. een test-item dat overeenstemt met een item uit de lijst). Bovendien worden sterke effecten gevonden van de seriële positie van het item dat met het test-item overeenstemt. Deze bevindingen wijzen erop dat een aantal theorieen over item-herkenning niet houdbaar zijn, zoals het z.g. "exhaustive serial-search" model, het "self-terminating serial-search" model alsmede de "parallel-search" modellen. De resultaten worden echter wel afdoende verklaard door een "direct-access" model. Volgens dit model kan het ophaalproces niet worden beschreven als een zoekproces door een verzameling geheugenrepresentaties van de <u>items</u>, maar veeleer als een zoekproces naar de contextuele retrieval-<u>cues</u> die verbonden zijn met het test-item.

Samenvatting

In Hoofdstuk 8 worden precueing-effecten bestudeerd in verscheidene keuze-reactietaken. In dit soort taak wordt de proefpersoon gevraagd zo snel mogelijk te reageren op een signaal uit een aantal mogelijke signalen. Bij elk signaal hoort een unieke reactie. De gezamenlijke evidentie uit een viertal experimenten toont aan dat de effectiviteit van precueing voornamelijk wordt bepaald door factoren die het response-decisie proces beïnvloeden, en niet door perceptuele of motorische processen. Verder licht Hoofdstuk 8 het standpunt toe dat het actiesignaal in een keuze-reactietaak kan worden opgevat als een retrieval-cue. Met deze retrieval-cue kan de gewenste response-representatie worden opgehaald uit een werkgeheugen met een beperkte capaciteit. Precueing van een deel van de verzameling stimulus-response alternatieven heeft tot gevolg dat de alternatieven opnieuw worden gerangschikt in het werkgeheugen. Deze herschikking vindt plaats voordat het actiesignaal wordt aangeboden, zodat het serieel zoeken naar de correcte response-representatie wordt vereenvoudigd, voor zover dit zoekproces zich tijdens het RT-interval afspeelt. De doelmatigheid van de precueing-signalen blijkt afhankelijk van "cue-compatibiliteit", een factor die de effectiviteit bepaalt waarmee het werkgeheugen opnieuw wordt gerangschikt. Cue-compatibiliteit is een tweeledig begrip, want het verwijst naar de "natuurlijkheid" van het verband tussen: (a) het precueing signaal en de response-representatie in het geheugen, en (b) het precueing signaal en de kenmerken van het actiesignaal.

De belangrijkste conclusies van deze studie over de eigenschappen van de zoek- en ophaalprocessen van het geheugen onderstrepen dat het meten van reactietijd in korte-duur geheugentaken een bijdrage kan leveren aan de kennis over mentale processen, die ten grondslag liggen aan het cognitief functioneren van de mens.

Summary

This dissertation addresses the question how information is retrieved from short-term memory. Short-term memory refers to task situations in which information is first presented and, after a short retention interval, an attempt is made to recall or recognize that information.

In cognitive psychology, short-term memory is conceived of as consisting of three phases. During acquisition, the information is encoded and stored. Subsequently, it is retained during a short retention interval, after which the information is retrieved and made available for some type of recall or recognition.

Performance in short-term memory has traditionally been measured in terms of the proportion of correct recall or recognition. This measure reflects memory <u>failures</u>. The present study employs a different approach, focussing on the cognitive processes underlying <u>successful</u> recall or recognition. The method eployed here attempts to discover the conditions and task demands that affect the duration of cognitive processes, in particular the processes resulting in successful memory retrieval.

Most of the experiments employ a positional-probe technique, in which a probe signal indicates the serial position of the to-be-recalled item from the memory list. This technique enables the measurement of vocal reaction time (RT) of single-item recall. RT is defined as the interval between the presentation of the positional probe and recall. In this way, the duration of the successful retrieval process is studied.

Research during the last two decades has underlined the importance of proper retrieval cues. A retrieval cue serves to guide the search process through the contents of memory, by means of which the required memory trace is retrieved. A proper retrieval cue is able to activate the required trace, due to the fact that it has become associated to the

trace, at the time of acquisition.

The positional cueing theory, as proposed by Sanders (1975), specifies the type of retrieval cues which are necessary in recalling a serial list of items. Temporal anchor points play a major role in creating "positional retrieval cues" attached to certain serial positions. The positional cues serve as points of direct access to the memorized list. This theory has served as the main guideline in devising the present experiments. The "probed-recall" paradigm, as mostly employed here, is adopted from a study by Sanders & Willemsen (1978).

The present study tests some specific hypotheses on memory performance, in a number of tasks that rely strongly on short-term memory. The following tasks have been used in this study:

(a) a probed-recall task; A single item has to be recalled. The serial position of the item is indicated by a positional probe, consisting of a light from a linear array (Chapter 2-6).

(b) a memory-search task; Recognition of a test-item as one of the items that have just been presented in a serial list (Chapter 7).

(c) a choice-reaction task; Reacting to an "action signal" drawn from a set of possible signal alternatives. Each signal requires a unique response (Chapter 8).

A number of experiments (chapter 2 and 3) confirm the predictions of positional cueing theory on the combined effects of (a) subjective grouping of the list during presentation and of (b) precueing a part of the list briefly in advance of the positional probe. Precueing reduces the number of possible probe locations. It is found that grouping reduces RT, in particular at the boundary positions of the sublists. It is concluded that grouping provides additional points of direct access to the list, thus reducing RT as well as error rate, whereas precueing preactivates direct access to one particular point in the list.

The results show that precueing has a <u>beneficial</u> effect on RT, but not on accuracy. This result has been obtained when the to-be-recalled item is retrievable via the preactivated point of access. <u>Adverse</u> effects of precueing have been found, on both RT and accuracy, whenever the preactivated retrieval pathway is inappropriate for retrieval of the

to-be-recalled item.

In Chapter 4, the time course of the precueing effects is studied over increasing intervals between the precue and the probe. RT is increasingly reduced with longer intervals, whereas accuracy remains unaffected. It is argued that these findings are well in accord with positional cueing theory.

Chapter 5 tests predictions on the effects of proactive interference (PI) from a preceding list. An experiment is reported, in which pairs of closely spaced lists were separated by a longer interval, to allow dissipation of PI between pairs of trials. In one condition, lists consisted of consonants only. In another condition, one of the lists from a pair consisted of a prefix (a digit) followed by consonants. It is found that in the second trial of each pair, PI causes an increase of RT and error rate, but only in the <u>first</u> part of the list. This suggests that PI impairs recall because of confusion between positional primacy cues associated to the first item of each list. The effects of PI increases when the first and second list contains a prefix. Hence, a prefix attached to both lists enhances this confusion.

In Chapter 6, the buildup of PI is studied within strings of six closely-spaced trials. The experiment addresses the question whether a greater number of prior trials contribute to PI than indicated by previous studies which merely measured proportion of correct recall. The results show that the main effect of PI occurs in the second trial, which agrees with the common finding reported in the literature.

In the light of these results, it is argued that the recall latency, that has been observed in the experiments of Chapters 2-4, does not reflect a buildup of PI over many trials. In these experiments, a great number of trials were presented in close succession and the results show relative long RTs in the primacy region of the serial-position curve. The present experiment rules out that this has been caused by a prolonged buildup of PI or by prolonged practice. The question remains as to the cause of this relative primacy disadvantage.

In Chapter 7, effects of grouping and of precueing are investigated in an item-recognition task (i.e., a "memory-search" task, Sternberg, 1969 b). Grouping of the lists occurred by inserting a temporal pause during the presentation of the items, so that the list was divided into two sublists. Precueing one of the sublists indicated that an item matching the test item can only occur in that sublist. The results show

linear and parallel set-size functions, that is, recognition latency (RT) is a linear increasing function of list length. This is found irrespective of grouping and of cueing.

Grouping substantially reduces the intercepts, but not the slopes of the set-size functions. Cueing enhances the beneficial effect of grouping, but only for positive test items (i.e., test items that match an item from the memory list). There are also strong effects of the serial position of the item that matched the test item. It is argued that these results neither support self-terminating serial models, nor exhaustive serial-search models. An adequate explanation of the results can be provided by a direct-access model, according to which there is no search at all across memorized <u>items</u>, but rather a search for contextual retrieval <u>cues</u> associated with the test item.

In Chapter 8, precueing effects are studied in various choice-reaction tasks. Converging evidence from four experiments indicates that the effectiveness of precueing is mainly determined by factors related to response-decision processes, instead of perceptual or motor processes. It is argued that the action signal in a reaction task can be conceived of as a retrieval cue for recall of the proper response representation. The response representation is stored in a limited-capacity memory stack. Precueing some of the response alternatives causes a rearrangement of the memory stack, in advance of the action signal, facilitating the search for the proper response. The effectiveness of precueing signals is shown to depend on "cue compatibility", a factor affecting the process of rearrangement of the stack. Cue compatibility is a twofold concept, which refers to the "naturalness" of the relation between (a) the precueing signal and the response representation and (b) between the precueing signal and features of the action signal.

The main conclusions of the present study, as summarized at the end of the first chapter, demonstrate that reaction-time studies of short-term memory contribute to our knowledge of human cognitive functioning.

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